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SOME RECENT DEVELOPMENTS AT LEADVILLE.

SECOND PAPER. THE OXIDIZED ZINC ORES.

G. MONTAGUE BUTLER.

HISTORICAL INTRODUCTION.

From 1860 to 1876, Leadville was a placer gold camp, and little actual mining was attempted, but the discovery of the carbonate lead ore in 1874 directed the attention of miners underground. At first, only lead and silver (in the form of cerussite and of cerargyrite) were mined, but, later, extensive deposits of oxidized manganese-iron ores were found; and deeper exploration revealed large bodies of sulphides—mainly galena, sphalerite, and pyrite. In 1891, ore chiefly valuable for its gold content was first encountered, and, following the depreciation in the value of silver in 1893, Leadville attracted wide attention as a gold district, although the other metals named were still mined in large quantities. Early in 1910, most of the larger known deposits had been worked out, many of the mines had been abandoned, and it was believed that the great camp with its production of over $380,000,000 was practically exhausted. Then, suddenly, the mining world was electrified by the announcement that enormous quantities of oxidized zinc minerals had been discovered; and it is with these ores that this paper deals.

DISCOVERY OF THE OXIDIZED ZINC ORE.

In the fall of 1909, the first shipment of oxidized zinc ore was made. It came from the Robert E. Lee mine but proved of too low grade to be profitable. It is not known, definitely, who first recognized the nature of the material but it was probably someone who had seen similar ore at Monarch, Chaffee County, or in the Hilltop mine not far from Leadville.

In May, 1910, a local assayer classified some material from the Hayden shaft of the May Queen mine as zinc ore, identifying it because of its similarity to that found at Monarch, with which he was familiar. He sent some specimens to the writer who classified them as smithsonite, calamine, and hydrozincite, and prepared brief descriptions of these minerals which were printed by the Colorado School of Mines and distributed gratuitously by the Leadville postmaster. The newly recognized zinc minerals were soon found in many properties, and before the end of the year nearly 10,000 tons of ore with an average zinc content of better than thirty per cent had been shipped to smelters. In spite of a controversy between the miners and smelters over smelting charges which tended to diminish the production of these ores during the early part of 1911, a total of over $3,000,000 worth of zinc in the form of carbonate and silicate was mined at Leadville during that year. This is about one tenth of the value of all metals produced in Colorado during 1911.

THE DISCOVERY OF NEW MATERIAL ON OLD GROUND.

The discovery of zinc carbonates at Leadville adds another to the many instances in which new and previously discarded material has been found in mines which have been worked for a long period of time. In the early days of the Leadville mines, ores of zinc were not only of no value but undesirable ingredients for the smelters. The discovery has therefore lagged behind the increased value and desirability of this type of ore.

Not a little controversy and discussion, some of it unnecessarily bitter, has taken place during the three years since the opening of the Leadville zinc ores as to the responsibility for the failure

of both practical miners and geologists to detect their presence. Practical mining men have criticized those geologists who had previously examined the district for not telling them of the presence of large tonnages of these ores. Geologists, on the other hand, have expressed surprise that practical men should have mined, assayed, and sampled so much ore, and that smelters should have put so many tons through their plants, without detecting its true nature. To those who will give the matter careful thought, such controversy will seem idle. Instances of this kind are by no means new, as a glance at the literature of the subject will readily show. It frequently happens that the districts where previously discarded ores have been found on old ground, have been examined by men of wide reputation both as engineers and geologists, and that the mines have been operated by practical men of recognized ability and acumen. The discussion seems especially unprofitable at Leadville because for many years zinc was an undesirable ingredient in the ores; and it is hardly surprising that the inherited habit of avoiding it and conducting no discriminating tests upon material generally discarded as valueless vein matter should have somewhat interfered with its discovery, even during the period when zinc had come to have a high commercial value.

It is true that the relatively high specific gravity of the smithsonite long ago attracted attention; but all curiosity seems to have been satisfied when it yielded no, or very low, assays for gold, silver, lead, manganese, and iron. Everyone called it lime, although fifty per cent too heavy.

GEOGRAPHICAL DISTRIBUTION OF THE ORE.

The ore under discussion is not confined to one mine or hill but most of the larger known bodies lie within an area extending north and south, two and a half miles, from Fryer Hill to Rock Hill, and east and west, four miles, from the foot of Carbonate Hill to No. 1 Resurrection shaft in Big Evans Gulch—in all, about ten square miles.

GEOLOGICAL POSITION OF THE ORE.

Workable deposits of oxidized zinc ore have been found in both the blue and the white limestone, though nearly all are in the former. The only ore-body in the white limestone known to the writer is in the Henriette. There, the ore was found about forty feet below the parting quartzite, and, when examined early in the winter of 1911–1912, it had been developed through a vertical distance of nearly forty feet.

The ore occurs throughout the blue limestone, from the parting quartzite up to the white porphyry, but seems to be more plentiful in the lower half of the lime. Although sometimes found along the contacts of the blue limestone with the parting quartzite or gray porphyry, it is by no means confined to those horizons; in fact, it appears equally plentiful away from these contacts.

The masses of ore vary greatly in size and the maximum is not yet known. That the average dimensions of these deposits will compare favorably with those of the other oxidized ore-bodies seems probable.

In shape, the deposits of oxidized zinc ore are as irregular as are the other replacement bodies of the district. Tendencies toward lenticularity along the bedding planes or contacts probably exist but were not apparent at the time of the examination; the vertical dimensions were often as large as the horizontal in the masses of ore then exposed.

The contact of the ore and the barren limestone is frequently quite sharply defined and of the irregularly curving nature characteristic of deposits formed by metasomatic replacement, but in some places there is an insensible gradation from barren lime to good ore, indicating that there has been some impregnation with, as well as replacement of the lime by, zinc carbonate.

Several who are familiar with the district have expressed the opinion that the smithsonite and calamine usually occur in close proximity around the oxidized iron and lead ores, but observation shows many violations of this rule. At points in the Adams and Monte Cristo, zinc carbonate and silicate lie directly below,

and in contact with, mixed sulphides, proving that the former could not have been formed by *vertically* descending solutions.

NATURE OF THE ORE.

The valuable portion of the ore consists of smithsonite (carbonate of zinc), calamine (hydrated silicate of zinc), and hydrozincite (hydrated carbonate of zinc). The first greatly predominates over the rest in the majority of cases, and the last is rarely identifiable.

The smithsonite varies in color from white to dark reddish or yellowish brown, is usually massive and quite opaque, and, with the exception of the small crystals mentioned later, it has a dull luster. In hardness, it varies from earthy softness up to a condition which a knife scratches with difficulty. All grades of porosity occur; some specimens absorb water like a sponge, while

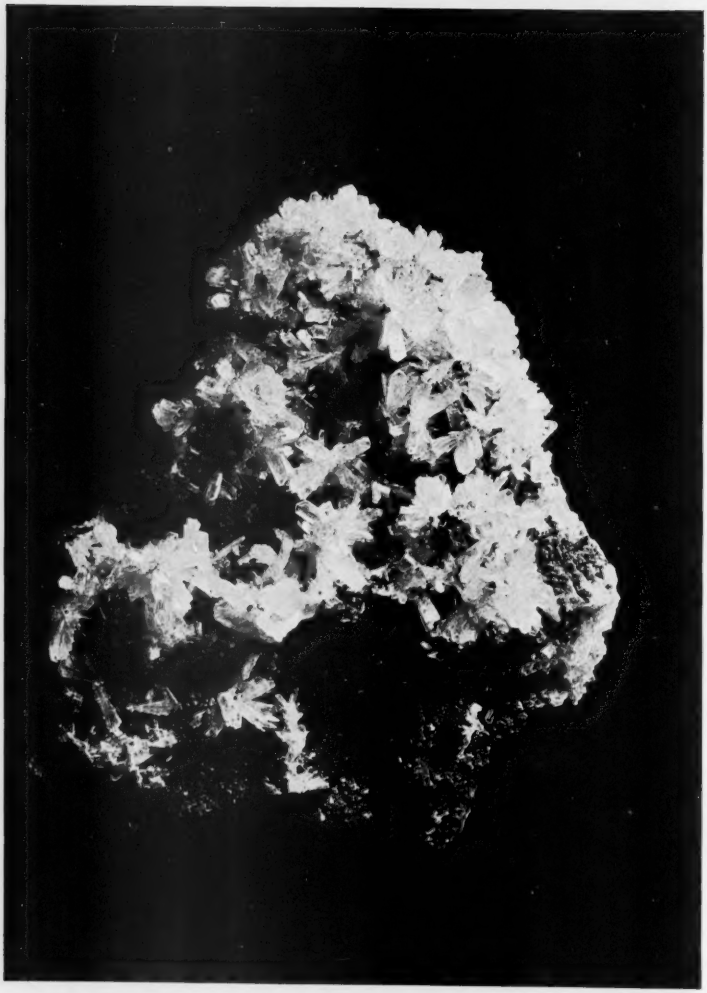
FIG. 1. Sample No. 15. Cellular smithsonite.

other varieties are very compact. The grains may be so large as to show cleavage faces or the mineral may be cryptocrystalline. Some specimens are cellular as shown in Fig. 1; and, when this structure is present on a smaller scale, the ore is a typical "dry-bone." Even the more compact varieties contain cavities with mamillary, botryoidal, or stalactitic surfaces which are often

FIG. 2. High grade smithsonite and calamine ore.

covered with a druse of tiny, warped rhombohedral crystals of smithsonite, or, less frequently, with a little psilomelane.

The calamine is always crystalline and occurs as a drusy lining to cavities in the smithsonite. Fig. 2 shows a piece of ore of



Calamine Crystals on Psilomelane and Smithsonite.

this type—not a carefully selected mineral specimen. In mass, the mineral is pure white, but individual crystals are colorless and perfectly transparent. The irregular, calamine-lined cavities vary from a fraction of an inch to a foot or more in diameter, with two or three inches as a probable average. In many places the calamine is so plentiful as to form a very considerable proportion of the ore.

The crystals vary from an eighth to three quarters of an inch long, with three eighths of an inch a common dimension. In appearance, they are decidedly tabular parallel to the brachy-pinacoid and are typical in every way. Two habits are found. In the commoner, the termination is a blunt macro-dome with a steeper macro-dome and a brachy-dome as occasional, inconspicuous additional forms (see Plate I.). The termination of the rarer habit consists of a very prominent brachy-dome and a less evident macro-dome. A second brachy-dome is often shown, and another macro-dome is sometimes present. Both types display a blunt-angled prism and a vertically striated brachy-pinacoid; and a second, inconspicuous prism is not infrequent. The basal-pinacoid has not been noted, and only one small pyramid face has been seen; it was modifying the first habit. No doubly terminated crystals have been noted. The first habit closely resembles Joplin marcasite in form, while the second looks like a flat cold-chisel.

The crystals often radiate from numerous centers all over a surface, giving the mass a botryoidal appearance as shown in Fig. 3, and the edges of such crusts have a coarsely radiating structure. Often two crystals are united along the brachy-pinacoids, the plane of union simulating a twinning plane. Sometimes several individual crystals are thus combined but sheaf-like and coxcomb-like effects are not nearly so common as familiarity with the habit of the mineral elsewhere would lead one to expect. Rarely, a few isolated crystals are scattered over a surface as shown in Plate I. The crystallization is sharp and the specimens are of great beauty and mineralogical and crystallographic interest and value.

The hydrozincite occurs infrequently as a dull lustered, white, soft, earthy alteration of the smithsonite. Doubtless it is present as an impurity in the smithsonite more commonly than can be ascertained visually.

In connection with the search for the oxidized zinc ores, a new mineral and a new variety of a previously classified species were discovered. The first is an oxide of manganese and zinc, and the

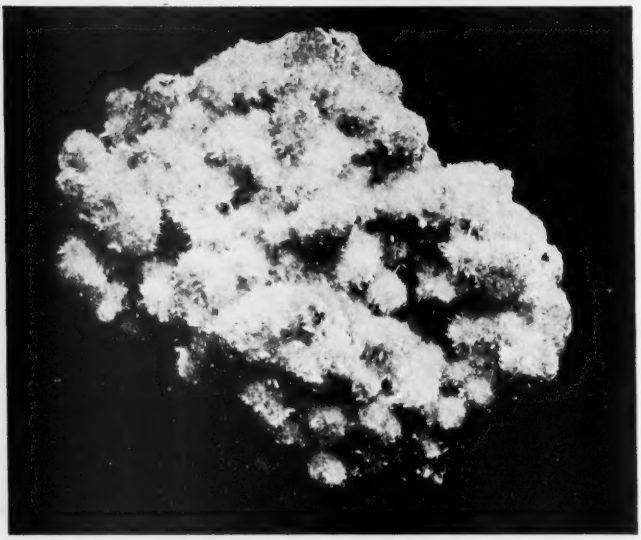


FIG. 3. Botryoidal druse of calamine.

second is an aragonite containing variable proportions of zinc—from almost none up to ten per cent. Both have been named by the writer, the former wolftonite, and the latter nicholsonite. A complete description of the wolftonite is now being prepared.

The nicholsonite is identical with aragonite in all but three particulars. Those specimens with high percentages of zinc have a higher specific gravity than aragonite, show a decided adaman-

tine rather than a vitreous luster, and have a better cleavage (good pinacoidal and poor prismatic) than pure aragonite. The variety was found in the oxidized iron-manganese ore in the

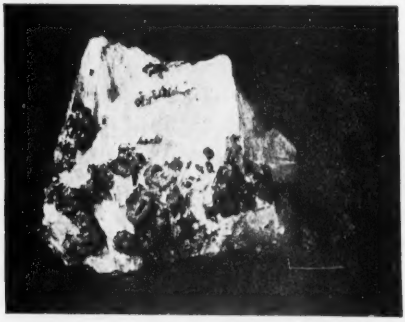


FIG. 4. Nicholsonite with psilomelane.

blue limestone, and was named after S. D. Nicholson of the Western Mining Company who brought it to the attention of the writer.

ORIGIN OF THE ORE.

The oxidized zinc minerals were undoubtedly originally deposited as the sulphide—sphalerite or blende—above the positions where they are now found, and were associated with a large proportion of the sulphides of lead, iron, and silver. This deposition took place at considerable depth—well below the ground-water level, where no oxidation could occur. As time passed, the erosion of the overlying beds and the depression of the ground-water level finally brought the upper sulphide bodies to a point where they could be attacked by oxygenated surface water which seeped down along the bedding planes. The iron sulphide (FeS_2) first altered to sulphate ($FeSO_4$) and sulphuric acid (H_2SO_4) according to the following equation:

$$FeS_2 + H_2O + 7O = FeSO_4 + H_2SO_4.$$

This sulphate of iron quickly oxidized to various other sulphates, thus:

$$2FeSO_4 + O = Fe_2S_2O_9,$$
$$2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O.$$

The very soluble products thus formed dissolved and part of them worked down the bedding planes for considerable distances where they were precipitated in the positions where now found by some such reaction as the following:

$$Fe_2S_2O_9 + 2CaCO_3 = 2CaSO_4 + Fe_2O_3 + 2CO_2.$$

Most of the hematite (Fe_2O_3) thus formed was later altered to limonite ($2Fe_2O_3 + H_2O$) by hydration.

The next mineral to be attacked was probably the galena (PbS). It may have altered directly to sulphate in the same way as the iron sulphide did but the process was hastened by reaction with some of the neutral iron sulphate, thus:

$$PbS + Fe_2(SO_4)_3 = PbSO_4 + 2FeSO_4 + S.$$

The anglesite ($PbSO_4$) thus formed is very insoluble, so most of the lead remained in its original position where it was gradually converted almost entirely to the carbonate-cerussite. Most of the sulphur oxidized to SO_2 and H_2SO_4, although some native sulphur occurred with the anglesite.

The sphalerite (ZnS) then altered in exactly the same way as the galena, but the resulting sulphate, being very soluble, was carried a long way down the bedding planes—even further than the iron sulphates—before it was precipitated by the action of calcium carbonate according to the following equation:

$$ZnSO_4 + CaCO_3 = ZnCO_3 + CaSO_4.$$

Later, some of the smithsonite ($ZnCO_3$) was changed to calamine ($Zn_2SiO_4 + H_2O$) by some such reaction as this:

$$2ZnCO_3 + SiO_2 + H_2O = (Zn_2SiO_4 + H_2O) + 2CO_2.$$

Lastly, the silver sulphide originally in the galena was converted into silver sulphate in the same manner as that outlined in the case of the lead and zinc. Silver sulphate (Ag_2SO_4) being somewhat soluble, part of it worked downward away from the lead carbonate, but a large proportion was deposited in the latter as some halogen compound, thus:

$$Ag_2SO_4 + 2NaCl = AgCl + Na_2SO_4.$$

NaCl (halite or common salt) is, of course, present in all ground water.

The formation of the oxidized manganese compounds found in connection with the oxidized iron deposits is not discussed here as their primary condition and the reactions involved are somewhat problematical and are believed to have no bearing upon the formation of the oxidized zinc ores.

As a result of the process outlined, iron oxides should occur below bodies of argentiferous lead carbonate, with zinc carbonates and silicates at still greater depth. The word *below* in the previous statement should not be interpreted *horizontally below.* In most cases the solutions doubtless worked down the gently dipping bedding planes, although there was doubtless some vertical movement where faults and fissures or joints were encountered.

In the manner suggested, downward flowing solutions may have passed below, and deposited their contents directly beneath, unaltered sulphides if the latter happened to be in a less pervious horizon and were thus protected from oxidation.

If the theory just sketched is correct and is applied literally, it appears safe to assume that each deposit of argentiferous lead carbonate is accompanied by iron oxide and zinc carbonate and silicate bodies at increasingly greater depths, but there are probably many exceptions to this rule due to difference in the character of the solutions, country rock, pressure, and other factors. Nevertheless, it is worth while prospecting for zinc carbonate and silicate ores down the dip below all large lead carbonate or iron-manganese oxide stopes. Due allowance should be taken of all faults or fissures encountered in such a search. Old water courses may furnish keys to the problem in some cases, and it should be remembered that zones through which solutions of oxidized ores have passed will probably contain no sulphides.

GRADE OF THE ORE.

All grades of ore are encountered; it varies from practically pure smithsonite containing about fifty per cent zinc down to zinc, iron, and manganese impregnated limestone running fifteen per cent, or less, in zinc. Ore containing twenty-seven per cent, or more, zinc can be mined profitably under present conditions.

The grade often changes rapidly and decidedly from point to point in a deposit, and continual sampling and assaying are required in order properly to direct mining operations.

POSSIBILITY OF VISUAL DETERMINATION OF THE GRADE OF THE ORE.

Owing to the lack of uniformity in grade just mentioned it becomes highly desirable to differentiate visually between different grades. In order to determine the possibility of this, a large number of samples were analyzed for zinc, and some of the results are tabulated in Table I.

A little study of this table convinces one that it is impossible to judge visually of the grade of the ore. Numbers five and ten are identical in aspect yet differ eight per cent in zinc content; numbers three and four, and eight and nine, are utterly dissimilar in appearance yet the first pair differ by only one and three tenths per cent, and the last pair differ by only three tenths of a per cent in zinc content. The examination of additional samples of known grade only serve to emphasize more strongly the impossibility of distinguishing visually between the rich and the leaner ore. The only statement on this point that it appears safe to make is that large amounts of calamine are more apt to be found in high-grade than in low-grade ores.

POSSIBILITY OF DETERMINING THE GRADE OF THE ORE BY BLOWPIPE OR QUALITATIVE CHEMICAL TESTS.

When the finely pulverized ore was strongly heated on charcoal with the reducing flame of a blowpipe, all grades of material tested (none ran lower than fifteen per cent zinc) yielded a

TABLE I.

DATA ON VARIOUS GRADES OF OXIDIZED ZINC ORE FROM LEADVILLE.

Description of the Ore.	Per Cent. Zn.	Observed Specific Gravity.	Calculated Specific Gravity.	Effervescence in Dilute HCl.
1. Light gray; granular with cavities; considerable pyrite and other sulphides visible	17.7	3.5	3.8	Very slight.
2. Reddish brown; earthy	20.9	2.7	3.6	Vigorous.
3. Reddish brown; earthy with cavities	22.4	2.7		Vigorous.
4. White; finely granular and compact to earthy	23.7	2.9	3.6	Considerable.
5. Brown; cryptocrystalline; many cavities lined with druses of smithsonite crystals, often underlaid with psilomelane	30.4	3.8		Considerable.
6. Light gray; very finely granular; cavernous; occasional druses of scalenohedral calcite	31.4	3.9		None.
7. Dark brownish red; cryptocrystalline; many cavities with druses of smithsonite crystals; some psilomelane and calamine	31.5	3.9		Considerable.
8. White with a brownish tint; very finely granular with a spongy appearance; microscopic drusy cavities	32.4	3.9		None.
9. Same as No. 7 but contains no calamine or psilomelane	32.7	3.9	4.0	Considerable.
10. Same as No. 5	38.4	4.0	4.1	Very slight.
11. Yellowish brown; microscopically spongy to very finely granular and compact	41.6	3.9	4.1	Considerable.
12. Brown and white; cryptocrystalline to earthy with a cavernous appearance; cavities wholly or partly filled with calamine	45.4	3.7		Considerable.
13. Same as No. 12 except that some hydrozincite is recognizable	45.4	3.9		Considerable.
14. Yellowish brown; very cavernous with thin, plane walls	46.0	3.9		Very slight.
15. Light yellowish brown; finely granular; cavernous	46.4	4.0	4.2	Considerable.

sublimate of zinc oxide, yellow when hot and white when cold. After this sublimate was moistened with dilute cobalt nitrate and again heated, it assumed a bright green color. As this test, which is distinctive of zinc in any combination, was apparently obtained with as much ease from low- as from high-grade ores, it is evident that the good ore cannot be differentiated from the poor material by use of the blowpipe. Degree of effervescence of fragments in dilute hydrochloric acid (three parts of water to one of acid) is not of much avail for this purpose either, although, as is shown in Table II., only low-grade ore effervesces vigorously.

TABLE II.

ANALYSES OF OXIDIZED ZINC ORES FROM LEADVILLE.

	Number of the Sample. See Table I.						
	1	2	4	9	10	11	15
Zinc	17.7	20.9	23.7	32.7	38.4	41.6	46.4
Lime	.8	.3	.6	.3	.4	.3	.9
Magnesia	.8	1.1	.7	2.2	2.0	.4	.5
Silica	4.0	22.4	33.6	3.3	3.8	8.7	.9
Iron	17.0	14.7	5.4	12.2	5.1	3.5	2.2
Sulphur	.6	——	——	——	——	——	——
Alumina	.4	2.2	2.8	.4	.2	.2	.2
Manganese	11.2	2.1	2.0	——	6.0	2.8	——
Insoluble	4.4	24.8	34.6	3.8	4.2	9.0	2.2

POSSIBILITY OF DETERMINING THE GRADE OF THE ORE BY ITS SPECIFIC GRAVITY.

In order to discover whether the specific gravity stood in any definite relation to the grade of the ore, nearly fifty specimens were analyzed and their specific gravities determined on a suitably equipped analytical balance. It was found that they all absorbed water slowly but at varying rates, for many hours, and that the weights in water were, therefore, continuously changing. In order to secure comparable data, particles weighing about one gram were allowed to soak fifteen minutes before weighing. This did not give the true specific gravity but represented the specific gravity of an ore with its pores nearly filled with air. Results secured in this way in the case of fifteen samples are

tabulated in Table I. under the heading "Observed Specific Gravity." In consequence of these and many other tests, it can be said that an ore with a specific gravity determined in this way of less than 3.3 is in all probability of too low grade (under twenty-seven per cent zinc) to be mined profitably at present. No exception to this statement was discovered by the writer. Some low-grade ores have a specific gravity of above 3.3 (see No. 1) but they are very rare and contain visible sulphides.

A very simple, rapid method of making this test is to place a tiny fragment of the massive smithsonite comprising the groundmass of the ore to be tested in methylen iodide, which has a specific gravity of 3.32. If the fragment floats on the surface, the ore is too poor to mine profitably or to require assaying, while, if it sinks, it is of good grade. In applying this test, it was found convenient to use a glass bottle of small diameter as the liquid becomes dark colored with use. Its specific gravity then changes slightly and should be checked occasionally with an object of known specific gravity. If many tests are to be made, the fragments should be introduced into, and removed from, the methylen iodide by placing them in small glass tubes with constricted bottoms through each of which there is a small hole. When such a tube, containing a fragment of the ore to be tested, is placed in the heavy liquid, the latter flows through the hole, fills the tube, and the fragment rises or falls according as to whether it is lighter or heavier than the liquid; and its position can readily be noted. When a tube is removed from the bottle the methylen iodide quickly drains through the hole. This little apparatus can be easily made by anyone with a blowpipe and some glass tubing by fusing one end of the tube almost shut. It will be found convenient for taking the specific gravity of gems and other minerals.

The liquid used costs about a dollar an ounce and can be obtained through any dealer in assayers' or chemists' supplies. It should be kept in the dark and tightly stoppered when not in use, and may be diluted with benzol to any specific gravity between .88 and 3.32. By saturation with iodine and iodoform, the specific gravity may be increased to 3.6.

In order to determine whether the observed and the true specific gravities bore any relationship to each other, complete analyses of seven ores were made. The zinc was then figured to smithsonite, the lime and magnesia to dolomite, the silica to kaolin and quartz, the iron to siderite or limonite according to the appearance (and to pyrite if sulphur were present), the sulphur to pyrite, the alumina to kaolin, and the manganese to psilomelane (assuming that it contained fifty-five per cent manganese) or rhodochrosite according to the appearance. This data is given in Tables II. and III.

TABLE III.

PROBABLE MINERALOGICAL COMPOSITION OF OXIDIZED ZINC ORES FROM LEADVILLE.

	Number of the Sample. See Table I.						
	1	2	4	9	10	11	15
Smithsonite, $ZnCO_3$	34.0	40.2	45.6	62.9	73.8	80.0	89.2
Dolomite, $(Ca, Mg)CO_3$	4.8	4.6	3.9	8.5	8.0	2.2	4.0
Quartz, SiO_2	3.6	19.8	30.3	2.8	3.6	8.5	.7
Siderite, $FeCO_3$	34.1		11.2	25.2			3.8
Limonite, $2Fe_2O_3.3H_2O$		24.6			8.5	5.8	
Pyrite, FeS_2	1.1						
Kaolin, $Al_2Si_2O_7.2H_2O$	1.0	5.6	7.1	1.0	.5	.5	.5
Psilomelane, $MnO_2.H_2O+$					10.9	5.1	
Rhodochrosite, $MnCO_3$	23.4	4.4	4.2				
Insoluble less SiO_2	.4	2.4	1.0	.5	.4	.3	1.3
Totals	102.4	101.6	103.3	100.9	105.7	102.4	99.5

Assuming that the ores have the mineralogical composition given in Table III., it is easy to compute fairly closely what the specific gravity of such a mixture would be. This has been done and is given in Table I. It will be noted that there is not nearly as much difference between the calculated specific gravities of numbers one and fifteen as there is between the observed specific gravities of the same specimens. The logical conclusion is, therefore, that the low-grade ores tested are all of greater average porosity than the high-grade material.

METHOD RECOMMENDED FOR THE QUICK DETERMINATION OF THE GRADE OF THE ORE.

Probably the quickest method for quickly ascertaining the approximate grade of oxidized zinc ore is to place about a teaspoonful of the finely powdered material to be tested upon a piece of iron or steel barrel-hoop, one and a half to two inches in width. This charge should be introduced into the incandescent coals of a blacksmith forge which has been blown until little black smoke is evident. The iron should be sunk into a depression in the glowing coals so that they stand a half inch or so above the sample on all sides. Then the draught should be increased until the iron is heated white hot. Oxidized zinc ore will take fire at this point, burning with a bluish flame and emitting white fumes of zinc oxide. The density of these fumes varies with the grade of the ore. Experience enables one to judge within five per cent of the zinc content by this method which, although long known and practiced in some places, is unfamiliar to those in other localities. The scheme can be applied to ore of any grade as material assaying five per cent zinc will yield visible fumes.

EXPERIMENTS ON THE CONCENTRATION OF THE ORE.

While large amounts of oxidized zinc ore averaging better than twenty-seven per cent have been developed, the majority of the ore-bodies discovered are of lower grade. There are now in sight literally millions of tons of material running from fifteen to twenty per cent zinc. These await the discovery of a process whereby the metal content may be profitably extracted.

In order to determine whether the ore was amenable to ordinary types of concentration, a specimen containing a high proportion of quartz (No. 4) was pulverized to 100 mesh and the powder placed in methylen iodide. After some time there was a notable separation of the powder into two portions, one of which rose to the top of the liquid and the other sank to the bottom. When powdered to 200 mesh, the separation was much more rapid and satisfactory. The portion that rose was undoubtedly largely quartz, and there is no reason to doubt that the

powder which sank contained a much higher percentage of zinc than did the original sample. No analyses of the two products were made, however.

Another sample (No. 9) containing a considerable amount of dolomite was tested in the same manner but with practically negative results.

As the specific gravities of the other more important impurities are too nearly that of smithsonite to make gravitational separation possible, it would seem that this method of concentration is of too limited application to be worth serious consideration. It is doubtful whether even the rather rare siliceous ore could be milled very satisfactorily and profitably. Very fine grinding would probably be required in most cases, and that is expensive and the slimes produced would surely give trouble.

In another experiment, an ore high in limonite (No. 2) was pulverized to 200 mesh and then dropped in a thin sheet through the field of a powerful electro-magnet, but there was no appreciable separation of the magnetic and non-magnetic ingredients.

It is, then, evident that, with the exception of calamine, some psilomelane, and a little calcite, the minerals composing the ore are present in very finely divided condition. This fact must be considered if a process of concentrating the low-grade ore is sought; and it should then be remembered that the impurities comprise dolomite, siderite, limonite, quartz, psilomelane, rhodochrosite, and kaolin in varying proportions.

From the experiments conducted by the writer, it appears probable that the utilization of the low-grade ore is dependent upon refinement or alteration of smelting methods, or the discovery of a process of chemical extraction of the zinc, rather than upon the production of a high-grade concentrate.

A REVIEW OF THE EXISTING HYPOTHESES ON THE ORIGIN OF THE SECONDARY SILICATE ZONES AT THE CONTACTS OF INTRUSIVES WITH LIMESTONES.

By W. L. Uglow.

INTRODUCTION.

During the last ten years, the number of ore deposits which have been found at the contacts of intrusive igneous rocks with limestones has rapidly increased. This has been in part the result of the clearer understanding and the easier recognition of this type of deposits which the study of contact metamorphism and ore deposition has brought about. The investigation of the increasing number of deposits has naturally led to a discussion as to the exact manner in which such bodies of ore have originated. A number of different hypotheses have been advocated for the formation both of the ores and the contact metamorphic minerals which have been developed by the intrusive igneous rocks in limestones. There has been not a little controversy between those who advocate the different methods of genesis. As all geologists and mining engineers may not be entirely familiar with the arguments which have been presented by those who favor one or the other of the proposed hypotheses, and because more attention has been given to the origin of the associated ores than to the study of the very extensive portions of the contact zones where little or no ore has been found, the writer feels that the following critical review of the existing theories is warranted.

Inasmuch as the ores which are associated with these contact zones occupy but a small portion of the contact area, more attention will be given to the non-metalliferous portion than to that which is composed chiefly of ore bodies. The sources of information are the various published reports which have been written on those districts which are of economic importance, as

they constitute the major portion of the available literature on the subject. Those facts which seem to have general significance have been tabulated in the following pages, and it is hoped that the reader may obtain from these tables a clearer idea as to the relative amount of accurate observation which supports either one or the other of the two most important hypotheses. It is the writer's intention to follow this review of the literature by a paper based upon extensive field observation.

GENERAL CHARACTERISTICS OF LIMESTONE CONTACTS.

Distribution.—Contacts of limestones with intrusive igneous rocks occur in greatest number in the western part of the continent of North America. They are here developed along the borders of extensive batholiths of igneous rock which have invaded sedimentary series and which have been revealed at the surface by the erosion of the overlying covers. In the eastern part of the continent they are less abundant. Some important ones occur, however, in the Adirondacks, the highlands of New Jersey, and the Piedmont district. The metamorphosed sedimentary rocks here are mostly Algonkian or Paleozoic. The sediments in these eastern occurrences have probably been subjected to repeated dynamic metamorphism, so that all, or nearly all, evidence of early contact action has been completely obliterated. In the western occurrences, on the other hand, the invaded rocks are frequently of late Paleozoic or early Metazoic age, and the contact zones, except for weathering, remain today in practically their original condition. They furnish, therefore, excellent opportunities for critical study.

Invaded Rocks.—The sedimentary rocks into which the intrusives have made their way are not exclusively limestones. Shales, sandstones, and conglomerates are of frequent occurrence. There are, of course, gradations between all of these different types. Limestones frequently contain sand or clay; sandstones, lime, clay, or iron; while the shales may contain lime or sand. In nearly all of the western occurrences a variety of sedimentary rocks are present, and all of the main types of sediments with

the intermediate gradations are more or less extensively represented. Upon all of these sediments the intrusives have exerted contact effect, but the ore bodies which are occasionally found along the igneous contacts are most commonly developed in the limestone.

Associated Ores.—Many of the ore deposits which are developed along these limestone contacts are sufficiently extensive and of sufficient value to be of considerable commercial importance. This is particularly true in the case of iron and copper. Iron is found in such association as magnetite[1] and specularite;[1] copper occurs very frequently as chalcopyrite and bronite, tetrahedrite and cupriferous pyrites;[2] lead and zinc are occasionally found as galena and sphalerite;[3] native gold occurs in wollastonite at Chiapas, Mexico,[4] and in arsenopyrite on the Simillkameen River, B. C.;[5] platinum is found in wollastonite;[6] bismuth occurs as tetradymite and bismuthinite;[7] and silver[8] as argentite, associated usually with the copper deposits. Of the above-named metal-bearing minerals, iron and copper alone occur in bodies of sufficient size and value to be of commercial importance. In number and extent the iron deposits overshadow the copper, and it is only necessary to mention, in the case of copper, the camps at Clifton-Morenci, etc. Gold, silver, lead, and zinc are occasionally recovered as by-products.

[1] C. K. Leith and E. C. Harder, "The Iron Ores of the Iron Springs District, Utah," U. S. G. S., Bull. 338, 1908.

[2] E. C. Harder, "Iron Ores of Western and Central California," U. S. G. S., Bull. 430; F. L. Ransome, U. S. G. S., Prof. Paper 21 (Bisbee); W. Lindgren, U. S. G. S., Prof. Paper 43 (Clifton-Morenci).

[3] W. O. Crosby, "The Limestone-Granite Contact-Deposits of Washington Camp, Arizona," *Trans. A. I. M. E.*, XXXVI., 1905, p. 626.

[4] E. T. McCarty, "Mining in the Wollastonite Ore-Deposits of the Santa Fe Mine, Chiapas, Mexico," *Trans. Inst. Min. and Met.*, Vol. IV., 1896, pp. 169–189.

[5] W. H. Weed, "Ore Deposits near Igneous Contacts," *Trans. A. I. M. E.*, XXXIII., 1903, p. 734.

[6] L. Hundeshagen, "The Occurrence of Platinum in Wollastonite on the Island of Sumatra," *Trans. Inst. Min. and Met.*, July 21, 1904.

[7] W. H. Weed, "Ore Deposits near Igneous Contacts," *Trans. A. I. M. E.*, XXXIII., 1903, p. 733.

[8] W. Lindgren, "Copper Deposits of the Seven Devils, Idaho," U. S. G. S., 20th Ann. Rept., Part III., p. 249; E. T. McCarty, *op. cit.*

Contact Metamorphic Minerals.—Associated with the metallic minerals are gangues of lime silicates and other contact metamorphic minerals, which show no marked variation whether iron or copper minerals preponderate in the ore.

Below is a list of the common "contact-metamorphic" minerals. They have been arranged in two distinct groups. Group 2 includes those minerals which contain elements such as boron, fluorine, chlorine or for other reasons later discussed may be admittedly the products of igneous emanation; group 1 contains the disputed series of what will be here termed the "silicate zone" group. It is mainly about this group that discussion has arisen.

GROUP 1.	GROUP 2.
Grossularite (Ca, Al, SiO_2).	Scapolite ($Ca, NaCl, Al, SiO_2$).
Andradite (Ca, Fe, SiO_2).	Vesuvianite (Ca, Al, F, SiO_2, OH).
Epidote (Ca, Al, Fe, SiO_2, H_2O).	Quartz (SiO_2).
Diopside (Ca, Mg, SiO_2).	Muscovite (H, K, Al, SiO_2).
Tremolite (Ca, Mg, SiO_2).	Albite (Na, Al, SiO_2).
Actinolite (Ca, Mg, Fe, SiO_2).	Axinite (Ca, Al, Fe, Mn, B, SiO_2).
Wollastonite (Ca, SiO_2).	Apatite (Ca, F, Cl, P_2O_5).
Biotite (Mg, Fe, Al, SiO_2, H_2O).	Tourmaline (Fe, Mg, B, Al, SiO_2).
Calcite ($CaCO_3$).	Fluorite (CaF_2).
Quartz (SiO_2).	

RELATIVE SUCCESSION OF THE TWO GROUPS.

Although the ore minerals are generally intergrown with the secondary silicates there is much which indicates a difference in the time of formation of the metalliferous and gangue minerals. Metallographic methods have been used on specimens, and in many cases a definite order of crystallization has been determined. Kemp has shown that at San Jose, Mexico,[1] and at White Knob, Idaho,[2] the ore-minerals were formed later than the silicates, and often cut through them as veinlets. Leith and

[1] J. F. Kemp, "The Copper Deposits of San Jose, Tamaulipas, Mexico," *Trans. A. I. M. E.*, XXXVI., 1906, pp. 178–203.

[2] J. F. Kemp and C. G. Gunther, "The White Knob Copper Deposits, Mackay, Idaho," *Trans. A. I. M. E.*, XXXVIII., 1907, pp. 269–293.

Harder, in their Iron Springs bulletin,[1] establish a succession of, first, silicate minerals and second, ore-minerals. Barrell[2] draws attention to the same feature at Marysville, Montana. Stutzer[3] determined the following order at the White Horse Pass mines in the Yukon: (*a*) pyroxene, and rarely magnetite, (*b*) magnetite, (*c*) garnet with a few metallic sulphides, (*d*) amphibole and the greater part of the sulphides, (*e*) calcite. At Morenci, Arizona, Lindgren[4] records the simultaneous crystallization of the lime-silicates and magnetite, together with some of the sulphides, while a great part of the sulphides are plainly of later formation, and cut the earlier minerals in veinlets and stringers. Spurr and Garrey[5] reach a similar conclusion in their observations upon the garnet-zones of Velardeña, Mexico; and Ransome,[6] in his new professional paper on the Breckenridge District, Colorado, concedes a dual stage.

HYPOTHESES OF ORIGIN.

The chief point on which geologists differ is as to the mode of origin of both the silicate and ore-minerals. The main views may be given in brief:

1. All the minerals of the contact-zone are the result of recrystallization of substances present before the limestone was metamorphosed. Ore-minerals and silicate-minerals are of the same origin. No introduction of material from the intrusive has occurred. This is the hypothesis which Rosenbusch,[7] Zirkel[8]

[1] C. K. Leith and E. C. Harder, "The Iron Ores of the Iron Springs District, Utah," U. S. G. S., Bull. 338, 1908.

[2] J. Barrell, "Geology of the Marysville Mining District, Montana," U. S. G. S., Prof. Paper 57.

[3] O. Stutzer, "Die Kontaktmetamorphen Kupfererzlagerstaeten von White Horse, Yukon," *Zeitschr. für prakt. Geol.*, March, 1909, p. 120.

[4] W. Lindgren, "The Copper Deposits of the Clifton-Morenci District," U. S. G. S., Prof. Paper 43, 1905.

[5] J. E. Spurr and G. H. Garrey, "The Copper Deposits of the Velardeña District, Durango, Mexico," ECON. GEOL., Vol. III., p. 688.

[6] F. L. Ransome, "Geology and Ore Deposits of the Breckenridge District, Colorado," U. S. G. S., Prof. Paper 75, 1911.

[7] Rosenbusch, "Mikroskopische Physiographie," 3d ed., p. 85.

[8] Zirkel, "Lehrbuch der Petrographie," 2d ed., Vol. I., pp. 587–588.

and Brögger advocate and may be entitled the old or original hypothesis.

2. A commonly accepted view at the present time is that of which J. F. Kemp[1] seems to be the chief supporter. It is almost diametrically opposed to that of Rosenbusch, Zirkel and Brögger. According to Kemp, the limestone furnishes only lime and some carbon dioxide to the minerals of the contact-zone. He maintains that the intrusive on cooling emits great quantities of vapors containing SiO_2, Al_2O_3, Fe_2O_3 FeO, MgO, H_2O, as well as metallic sulphides and oxides. The silica, alumina, and iron oxides unite with the lime of the limestone to form lime silicates. Of course, if the original limestone should contain silica, alumina, or iron oxide as impurities, they might well be used in the formation of the secondary minerals.

3. There are other views which seem more reasonable in that they take a sort of intermediate position with regard to the above-mentioned two:

(*A*) J. Barrell:[2] A period of metamorphism follows the intrusion, during which gases are expelled from the sediments, the volume contracts, and there is a general recrystallization. Subsequent to this comes a period of metasomatism, during which a replacement of the metamorphosed sediments takes place, the replacing material coming as eruptive afteractions from the intrusive. According to this view, the silica and alumina existing in carbonate rocks combine with the bases and set free a proportionate amount of carbon dioxide. The absolute amount of lime and magnesia is the same after the process is completed as before. The emanations, which proceed from the magma, during the metasomatic phase of the contact action, consist chiefly of silica, iron oxide, water, sulphur, besides, of course, other ore-producing compounds.

[1] J. K. Kemp, "Contact Deposits: Types of Ore Deposits," *Mining and Scientific Press*, 1911.

[2] J. Barrell, "Geology of the Marysville Mining District, Montana," U. S. G. S., Prof. Paper 57; "Physical Effects of Contact Metamorphism," *Am. Jour. Sc.*, 1902, pp. 279–296.

(*B*) A. C. Lawson:[1] The heated intrusive disturbs the ground-water circulation, and gives it new impetus to work over the rocks of the vicinity. This increased activity of the ground-water is responsible, then, for the formation of both the secondary silicates and the ores. In this way, Lawson avoids the necessity of looking for a contribution from the magma. In his own words: "The circulation would always be upward on the periphery of the hot mass. . . . Such a circulation of the heated ground-water would be quite competent to do all that is ascribed to magmatic waters, including the formation of lime-silicate zones."

(*C*) W. Lindgren:[2] There is a combination of a recrystallization of impurities with an introduction of large amounts of SiO_2 and Fe_2O_3, and small amounts of Al_2O_3, to form the secondary silicates. The ore-minerals are partly formed at the same time as the silicates, and are partly the result of a working over of the intrusives by hot waters. In his earlier work,[3] he states that the "metallic-minerals are intergrown with the various gangue minerals,—garnet, epidote, wollastonite, etc.—in such a manner that they must be considered as having a simultaneous origin. The theory of a subsequent introduction of the metallic ores is decidedly untenable." More recently, however, he has come to recognize more or less definitely a sort of dual stage in the formation of the contact-zones.

(*D*) C. K. Leith:[4] According to the hypothesis set forth by Leith and Harder in their Iron Springs bulletin, the secondary silicate zone is largely a recrystallization of constituents already in the limestone, combined with an expulsion of the excess calcium carbonate. This view does not by any means involve a total absence of infiltrated material from the intrusive, but its advocates maintain that the so-called contact-zone can be litholog-

[1] A. C. Lawson, "Types of Ore Deposits—A Review," *Min. and Sc. Press*, Feb. 3, 1912, p. 200.

[2] W. Lindgren, "Copper Deposits of the Clifton-Morenci District, Arizona," U. S. G. S., Prof. Paper 43, 1905.

[3] W. Lindgren, "The Character and Genesis of Certain Contact-Deposits: Genesis of Ore-Deposits," 1901, p. 726.

[4] C. K. Leith and E. C. Harder, "The Iron Ores of the Iron Springs District, Utah," U. S. G. S., Bull. 338, 1908.

ically divided into two parts, one part of which is formed entirely by recrystallization in the early stages of the metamorphism, and the other part by later addition of material in the way of emanations from the magma. The minerals which belong to the first class are those mentioned in the left-hand columns on pages 7 and 8, while those of the second class include among others those listed in the right-hand column on the same pages, together with the metallic minerals. It will be noticed that the non-metallic minerals of the latter class nearly all contain an element more or less foreign to sedimentary series, *e. g.*, boron, fluorine, chlorine, beryllium, etc. These are typically found in magmatic emanations. The metallic minerals may be either direct contributions from the magma, or hot water deposits resulting from the working over of the hot intrusives. Definite evidence is obtained in the area described of the earlier formation of the first class of minerals. The two periods no doubt overlapped, but there is a somewhat well-marked distinction in the matter of time.

The magnitude of the iron deposits of the West, especially as they occur in connection with acidic intrusives, makes it almost impossible to suppose that they have been formed in any other way than by direct introduction from the cooling magma.[1] The copper deposits, on the other hand, are low grade and are disseminated. The igneous rocks with which they are associated show the results of leaching by hydrothermal action, and also contain traces of copper. There seems to be no reason why the copper could not have been at least partially contributed by the hot waters that leached the intrusives.[2]

The last hypothesis seems to the writer to be the most probable. In the present paper, an attempt is made to collect and correlate facts that will tend to substantiate this hypothesis. During the discussion, the application of the expressions "secondary silicate zone," "contact-zone," etc., will be limited to that phase characterized by the presence of the minerals of the first class, as

[1] Personal communication.
[2] Personal communication.

mentioned above. It is freely admitted that minerals containing such elements as boron, fluorine, beryllium, etc., required for their formation a contribution from igneous sources.

TABLE OF COMPARATIVE EVIDENCE.

Setting aside the question of how and when the ore-minerals of the contact-zones were formed, the problem resolves itself into the following alternative: (*a*) Is the "secondary silicate zone" the result of a combination of the lime of the limestone with other oxides furnished directly by the intrusive, or (*b*) is it entirely the result of a redistribution and recrystallization of the impurities already in the limestone, without any contribution from the magma?

The evidence obtainable from published articles which deal with this question has been arranged in two columns in the following tabulated summary. Arguments from each individual publication are presented together, on one side or other of the center line according to the view to which they lend support. Facts which equally favor or oppose both hypotheses are not noted in the compilation. Letters and figures appended to the various paragraphs thus: (*A*, pp. 199–200) refer to the list of references on page 45 of this paper.

COMPARATIVE TABLE OF EVIDENCE SUPPORTING THE TWO OPPOSING HYPOTHESES OF ORIGIN OF SECONDARY SILICATE ZONES.

CRITERIA FAVORING THE HYPOTHESIS OF THE RECRYSTALLIZATION OF IMPURITIES TO FORM THE SILICATES, AND THE LATER INTRODUCTION OF METALLIC AND PNEUMATOLYTIC CONSTITUENTS.

1. The view that now appears to be generally accepted, *i. e.*, the introduction of ore minerals later than the formation of the silicates, favors to a certain extent the recrystallization hypothesis (*A*, pp. 199–200).

2. Garnet rock (grossularite) occurs along part only of the contact and coincides with the impure limestone layers (*B*, p. 630).

3. Wollastonite commonly occurs as a "reaction-zone bordering layers and nodules of chert in those portions of the cherty limestone nearest the granite or within several hundred feet of the contact. The relations are very clear, the chert masses, often with frayed and disintegrated margins, being separated from the enclosing crystalline limestone by zones from one to several inches broad of white massive wollastonite. . . . That the silica of the chert had

CRITERIA FAVORING THE HYPOTHESIS OF THE DIRECT CONTRIBUTION FROM THE MAGMA OF BOTH METALLIC CONSTITUENTS, AND MATERIALS FOR THE FORMATION OF THE SILICATES.

1. The largest contact zones seem to be found in association with acidic intrusives. Magmas of acidic composition are believed to be most richly provided with the so-called mineralizers (*A*, p. 191).

replaced the carbon dioxide of the limestone is

replaced the carbon dioxide of the limestone is obvious" (*B*, p. 634).

RECRYSTALLIZATION.

4. In the Washington Camp, Arizona, the garnet-zones are very persistent. They disregard the granite contact, and follow each a particular bed or horizon of impure limestone longitudinally through the district. "Of especial interest and significance among these is the garnet-zone at the base of the limestone, in the siliceous and argillaceous beds of passage between the basal quartzite and the limestone, and separated by the quartzite, from 100 to 200 feet thick, from the western granite" (*B*, p. 636).

5. "If the SiO_2 and Al_2O_3 have been derived from the granite, and the limestone has furnished only the CaO, MgO, Fe_2O_3, the garnet-zone should be a constant feature of the contact; or, at least, there is no apparent reason why it should fail, as it does, just where SiO_2 and Al_2O_3 are wanting in the limestone" (*B*, pp. 637–638).

6. In the White Knob Camp, Mackay, Idaho, the secondary silicate zone at the contact of the quartz porphyry and limestone is small. However, where

DIRECT CONTRIBUTION.

2. Kemp shows by analysis that the garnet-rock at White Knob is largely andradite, the calcium-iron garnet. He argues that the amount of iron

RECRYSTALLIZATION.

the intrusive completely engulfed fragments of limestone, an almost complete alteration to garnet had taken place. The explanation seems to be one of the amount of heat transferred to the limestone, and the temperature to which it was raised. Of course, the included fragments would be heated to a much higher temperature than the country rock in place (*C*, p. 285).

7. Diopside is the next abundant silicate after garnet, at White Knob. This is free from iron, and should be averaged up with the andradite in order to get a correct idea of the composition of the silicate zone. This would greatly reduce the percentage of iron required in comparison with the silica and alumina (*C*, pp. 287–288).

8. Kemp recognizes two periods in the formation of the contact zone; garnet, diopside, vesuvianite and epidote seem to have been formed first, while magnetite, chalcopyrite, pyrite and specularite were formed a little later (*C*, p. 289). This is a common feature in many of the camps, and it seems difficult to reconcile the phenomenon in so many cases with the hypothesis of direct contribution.

DIRECT CONTRIBUTION.

required for this mineral cannot be obtained from the limestone (*C*, pp. 286–7).

RECRYSTALLIZATION.

DIRECT CONTRIBUTION.

RECRYSTALLIZATION.

9. The amount of aluminous silicates present in the secondary zone at White Knob seems a strong argument against the introduction of materials, for the reason that Al_2O_3 is practically unknown in emanations from igneous rocks.

10. The invaded limestone at White Knob contains considerable percentages of impurities in the way of carbonaceous material, bands of chert, and beds of dolomitic limestone. There seems to be but little occasion for trying to account for these materials by direct contribution (*C*, p. 276).

11. The invaded sediments at the Bisbee Camp, in which the contact zone occurs, are, according to Ransome's own description anything but pure calcium carbonate. There are beds of chert, dolomite and shale interlayered with limestone. Even in the so-called pure beds of Escabrosa and Naco limestone, in which the copper ores occur, are found beds of chert, and others of pink calcareous shale. Examined with a lens these limestones show minute quartz grains, and tiny flakes of mica. Ransome gives analyses of the Naco limestone, for instance, but admits (p. 55) that on the average it contains

DIRECT CONTRIBUTION.

3. The original metallic mineral at Bisbee is pyrite. It occurs very intimately associated with the secondary silicates, and appears to have been crystallized at the same time as the silicates (*D*, p. 132).

noticeable amounts of silica, alumina, and iron oxides (*D*, pp. 28–56).

12. A thin section of the Naco limestone at Bisbee, near the contact, shows that, although it is apparently unchanged to the naked eye, it is "nearly one-third altered into a granular aggregate of quartz forming an irregular web inclosing residual kernels of calcite" (*D*, p. 83). (Why should the quartz enclose kernels of crystalline limestone, unless it was the result of recrystallization of chert already in the limestone?)

13. The sediments in the Clifton-Morenci Camp, in which the contact zone occurs, seem from Lindgren's descriptions to contain a considerable amount of silica, alumina, magnesia, and iron oxide, in the form of chert, shale, dolomitic bands, and brownish limestone. It seems hardly necessary to require the introduction of just these materials to form the silicates (*E*, pp. 62–73).

14. Lindgren finds the quartz grains in the intrusive rocks in the Clifton-Morenci Camp to contain abundant fluid inclusions. These inclusions contain usually a solid body resembling specularite.

4. "While the diorite-porphyries have changed the surrounding sedimentary beds but little by the heat and emanations of the magma, the quartz-monzonite-porphyries and the granite-porphyries have generally exerted a profound alteration, especially in the Paleozoic limestones and shales" (*E*, p. 85).

5. "When the dike enters the pure limestone of the Modoc formation, garnet forms in enormous quantities. A stratum of garnet and magnetite follows this bed for 2,000 feet between almost *unal-*

RECRYSTALLIZATION.

DIRECT CONTRIBUTION.

He regards it as a very curious fact that only very exceptionally do the secondary minerals of the contact zone contain such inclusions. "The metamorphism of the limestone to garnet, epidote, diopside, quartz, and other minerals took place under conditions of high temperature and pressure, and almost certainly in the presence of aqueous solutions in fluid or gaseous form." (These facts indicate that the quartz of the intrusive and the quartz of the contact zone have had quite different origins.) (*E*, pp. 214, 217.)

15. "The change in composition in the case of clay shales is extremely slight" (*E*, p. 162) (*E*, p. 130). (If the metamorphism is caused by addition of substances, how is it that shales become recrystallized and form silicates, and yet show only very slight changes in chemical composition?)

16. In the Clifton-Morenci district: Sandstones are altered to quartzites. Shales are altered to epidote-amphibole, schists and pyrite. Limestones are altered to iron-garnet, and diopside rocks (*E*, p. 127). (These are the natural recrystallizations of the respective sediments.)

tered Devonian and Cretaceous sediments (*E*, p. 127).

RECRYSTALLIZATION.

17. Lindgren gives figures in the Clifton-Morenci professional paper to show the tremendous transfusion of material that would be necessary on the direct contribution hypothesis for the change of limestone to garnet, provided there were no change of volume. To accomplish this result, 460 kilograms CaO and 1.19 kilograms CO_2 would have to be expelled per cubic meter, while 1,330 kilograms SiO_2 and 1,180 kilograms Fe_2O_3 would have to be added (*E*, p. 154). (This is demanding as much from the intrusive as the recrystallization theory demands from the limestone.)

DIRECT CONTRIBUTION.

6. Garnet formations (the largest of which is 200 feet thick) are often entirely enclosed by granite, and appear to have no relation to limestone (*F*, p. 472). (Limestones, however, are present in the immediate neighborhood.)

7. The general presence of copper sulphides in these garnet-reefs, together with an excess of silica, shown by the presence of quartz, gives the garnet-reefs a lode-like character, the garnet becoming a true veinstone, or gangue, for the copper ore (*G*, p. 889).

RECRYSTALLIZATION.

DIRECT CONTRIBUTION.

RECRYSTALLIZATION.

18. At San Jose, Tamaulipas, Mexico, diorite-porphyry intrudes Cretaceous limestones and produces garnet zones. Kemp admits that the limestone, although to all appearance pure $CaCO_3$, contains cherty and shaly beds. Analyses show the limestones to contain from 4 to 9 per cent. of insoluble constituents. This is all the recrystallization hypothesis requires (*J*, p. 189).

19. In J. F. Kemp's article entitled "Copper Deposits at San Jose, Mexico," appears the following statement: "Dr. W. L. Austin has called my attention to a very striking illustration of these relations"

DIRECT CONTRIBUTION.

8. In the Globe Camp, Arizona, "the metamorphic action of the diabase, even when intruded in great masses into quartzites and limestones, is remarkably slight. The only effect discoverable in the Globe limestone is the development of a little coarser crystalline texture which may extend for only a few inches from the contact. Even this alteration is not always recognizable" (*H*, pp. 85–86). (This is rather difficult of explanation on the recrystallization hypothesis, especially as the Globe limestone contains shaly and arenaceous beds.)

9. Kemp states that the recrystallization of a limestone would require the production of cavities which in reality are not found. The silicate rock is a fairly dense and solid variety (*J*, p. 202). (The recrystallization takes place under great pressure. This would eliminate cavities.)

(zone of silicates following certain layers) "at Sacrificio Mountain, Nombre de Dios, Durango, Mexico, in which the zones are wollastonite. It would seem from this as if the siliceous beds yielded wollastonite, and the neighboring calcareous beds marble. No doubt these cases strongly favor recrystallization in situ" (*J*, p. 198).

20. In the Elkhorn District, Montana, "the strata about the Black Butte stock dip toward it from all sides, indicating a settling-in of the crust upon the partially cooled and consequently contracted magma" (*K*, p. 444). (This might be due to a contraction of volume on the part of the limestone.)

21. The Keene limestones (Elkhorn) "being less argillaceous than the Starmount limestones, the garnet sinks to a subordinate amount and the siliceous impurities combine with the lime and magnesia, predominantly as a pyroxene and no doubt approaching a pure diopside in composition" (*K*, p. 547). (This shows that the garnet (grossularite) is definitely related to the impurities in the limestone.)

22. Pure limestones in the Elkhorn District, and but four feet from the intrusive granite are con-

RECRYSTALLIZATION.

verted into "white, coarsely granular marbles, whose only impurities are 5 per cent. of wollastonite in scattered microscopic crystals. . . . The metamorphism in rocks such as the Starmount siliceous and argillaceous limestones is strongly marked for distances of a quarter to half a mile from the intrusions and in a minor degree extends much farther" (*L*, pp. 291–292).

23. "Even the most massive phases of the garnet rock appear in thin section to be made up of an aggregate of fairly well-formed crystals. . . . The iron ore is not intermixed with the garnet. . . . Bodies of yellowish-green garnet in thin section are seen to be an aggregate of more or less idiomorphic crystals of doubly refracting garnet, with angular spaces be-

DIRECT CONTRIBUTION.

10. "Garnet and epidote are not confined to the limestone, but are also abundant when greenstone and gray granite are the country rock" (*M*, p. 63*A*). "Epidote, tremolite, garnet are developed in all the older rocks (granodiorite among the others), and apparently less readily in the limestone than in the other rocks" (*M*, p. 109*A*).

11. The presence of "quartz-blouts" around the periphery of the porphyry in the Robinson Mining District seems to indicate a transfusion of silica from the intrusive to the limestone (*N*, p. 329). (This phenomenon belongs to a phase of contact action distinctly later than the formation of the "secondary silicate zone.")

tween the crystals filled with calcite" (*N*, p. 315). Robinson Mining District, Nevada.

24. The secondary silicates, garnet and colorless pyroxene, which are formed in the crystalline limestones of the eastern Adirondacks, are considered by Kemp as formed by dynamic metamorphism. In this process there can be no addition of material (*O*, p. 247).

25. Limestones in the Adirondack region are interlaminated with different varieties of gneiss (garnetiferous and micaceous, pyroxenic and hornblendic). The latter show a great amount of crumpling and crushing, while the former are massive (*P*, p. 265). The evidences of contraction of volume are not preserved in limestone.

26. Garnet and ore have a different time of formation in the Velardeña District, Mexico (*Q*, p. 709).

12. Spurr and Garrey show in the contact zone at Velardeña, Mexico, a somewhat definite order of deposition of the contact minerals, the later ones *replacing* the earlier ones (*Q*, p. 709).

13. Yung and McCaffery find a very intimate association of chalcopyrite and garnet in the San Pedro District. They are so mixed as to indicate simultaneous formation (*R*, p. 355).

RECRYSTALLIZATION.

27. In the Elkhorn District, Montana, ore occurs in a garnet-diopside stratum (altered limestone), 15 to 18 inches thick, dipping 55° to the east, and carrying gold in bismuthinite and bismuth telluride (tetradymite). This ore stratum is conformable with the adjacent beds, but differs from them in composition. (This selective action of metamorphism must be closely related to the original composition of the stratum.) (*S*, p. 734.)

DIRECT CONTRIBUTION.

14. "In many localities as in the Organ Mountains, and the Tres Hermanas, complete garnetization takes place, the bedding and locally even the fossils being preserved" (*T*, p. 42).

15. Garnet, epidote, augite, anthophyllite are abundantly developed in diabase, where it cuts quartzite, and sparingly in the quartzite (*U*, p. 225). (This seems to indicate that the formation of these silicates was independent of lime-holding sediments.) Harder, however, suggests that probably the quartzite is only a silicified limestone.

16. "The characteristic feature (of contact deposits) is the association of the oxides of iron with

28. Iron Springs, Utah: "If SiO_2 and Al_2O_3 have been added from without, it is a remarkable coincidence that they should have been added in so nearly the same proportion as in the fresh rock, especially when it is remembered that their proportion in the fresh limestone is not determined by silicate ratios, but rather by the abundance of chert" (*W*, p. 33).

29. It will be noted that the composition of the altered rock is essentially that of a calcareous residual clay (*W*, p. 33).

30. "In the Iron Springs district the field evidence does not positively prove or disprove important volume change, but there is no apparent field evidence to contradict the evidence for diminution

sulphides, a combination practically unknown in fissure-veins" (*V*, p. 717).

17. In the Seven Devils District, Idaho, diorite cuts limestone. Irregular bodies of bornite, chalcocite, and a little chalcopyrite occur in the limestone, simultaneous in crystallization with garnet, epidote, quartz, calcite and specularite (*V*, p. 722).

18. Iron Springs, Utah: On the hypothesis that Al_2O_3 and SiO_2 are not introduced it is necessary to grant the addition of Na_2O and NaCl from the intrusive (*W*, p. 77). NaCl is very commonly carried in magmatic waters (*W*, p. 78).

19. Iron Springs: Ore-bearing fissures cut the andesite and the limestone, and carry as gangue minerals: apatite, garnet, amphibole, and pyroxene (*W*, pp. 76–78).

of volume here calculated. The limestone, though tilted away from the andesite laccoliths, nowhere shows evidence of crumpling or crowding where the bedding can be observed. In the altered phase the bedding has been destroyed, and it is easy to conceive that this structurally amorphous zone may represent only a part of the volume of the original rock, the calcium carbonate having been driven off and the other constituents concentrated. The change in volume of the limestone would scarcely be expected to stand out conspicuously in the field-relations, for it has occurred, if at all, in the band which now does not show original textures or structures, by which change of volume can be measured in crumpling or folding" (*W*, p. 35).

31. Iron Springs: Unaltered Homestake limestone shows on analysis the presence of SiO_2 and Al_2O_3 varying in amount from 4.9 to 10 per cent. (*W*, p. 26). Under the microscope it shows minute grains of calcite, with scattered grains of FeS_2, Fe_3O_4, chert (*W*, p. 25).

32. Iron Springs: "The introduction of ore took place after the development of the silicated contact

phase, as is demonstrated by its occurrence in fissures that intersect this phase" (*W*, p. 27).

33. Marysville, Mont.: The intruded rocks afford sufficient impurities in the way of SiO_2 and Al_2O_3 to form silicates (*X*, pp. 8–9).

34. Marysville, Mont.: "The original metamorphism shows no evidence of infiltration, thin concretionary bands of calciate still existing between siliceous bands. Yet calcite, both here and elsewhere, is found to be a mineral which readily suffers change in the presence of siliceous and sulphurous solutions" (*X*, p. 145).

35. Marysville, Mont.: "In the outer parts of the metamorphic zone a considerable amount of calcareous hornstones and smaller amounts of marble are present, a composition, which, contrasted with that of the inner parts of the zone, is evidence that metamorphism without metasomatic infiltration has been the prevalent process in the outer portions" (*X*, p. 145).

36. Marysville, Mont.: "These same laminæ of hornstone are formed of diopside, tremolite, actino-

lite, biotite, muscovite, quartz, and feldspar, and in many places small amounts of calcite. These mineral compositions are such as would result from the simple metamorphism of the Empire and Helena formations, which are of a mixed sedimentary character" (*X*, p. 145).

37. Marysville, Mont.: "In all cases where simple metamorphism and metasomatic infiltration are observed occurring together the latter is seen to take advantage of brecciated or fissile structures, either following the brecciation or accompanying it, but penetrating only slightly into the rock" (*X*, p. 145).

38. Marysville, Mont.: Near Sawmill Gulch, on Silver Creek, a stratum of light-gray diopside hornstone about 50 feet thick may be traced for one-third of a mile. "The dip is less than 10°, and typical Helena limestone is found stratigraphically both above and below. This flat dip and the lack of evidence of direct association with faults, as well as the presence of unmodified rock both above and below, negative the idea that the diopside is here the result of the infiltration of siliceous waters" (*X*, p. 147). (This is directly the opposite of what Lind-

gren finds to be true in the Clifton-Morenci Camp, where the greatest contact effects have been produced in almost pure limestone.)

39. Ore minerals at limestone-granite contacts are exceptional occurrences. If the ore minerals and the secondary silicates were all magmatic emanations, how can Kemp explain the almost universal presence of the one and the exceptional occurrence of the other? (A. C. Lawson: "Types of Ore-Deposits.—A Review," *Min. and Sc. Press*, Feb. 3, 1912, p. 200.)

REFERENCES FOR PRECEDING TABLE.

A. J. F. KEMP. Contact-Deposits: Types of Ore Deposits. *Min. and Sc. Press,* 1911.

B. W. O. CROSBY. The Limestone-Granite Contact-Deposits of Washington Camp, Arizona. *Trans. A. I. M. E.,* XXXVI., 1905, p. 626.

C. J. F. KEMP AND C. G. GUNTHER. The White Knob Copper Deposits, Mackay, Idaho. *Trans. A. I. M. E.,* XXXVIII., 1907, pp. 269–293.

D. F. L. RANSOME. U. S. G. S., Prof. Paper 21 (Bisbee).

E. W. LINDGREN. U. S. G. S., Prof. Paper 43 (Clifton-Morenci).

F. GEORGE SMITH. The Garnet-Formations of the Chillagoe Copper Field, North Queensland, Australia. *Trans. A. I. M. E.,* XXXIV., 1904, p. 467.

G. W. P. BLAKE. Copper-Ore and Garnet in Association. *Trans. A. I. M. E.,* XXXIV., 1904, p. 886.

H. F. L. RANSOME. U. S. G. S., Prof. Paper 12 (Globe, Ariz.).

J. J. F. KEMP. The Copper-Deposits at San Jose, Tamaulipas, Mexico. *Trans. A. I. M. E.,* XXXVI., 1905, p. 178.

K. W. H. WEED AND J. BARRELL. Geology and Ore Deposits of the Elkhorn Mining District, Jefferson County, Montana. U. S. G. S., 22d Ann. Rept., Part II.

L. J. BARRELL. Physical Effects of Contact Metamorphism. *Am. Jour. Sc.,* 1902, p. 279.

M. R. W. BROCK. Boundary Creek District, B. C. Summary Reports, Can. Geol. Survey, 1901, p. 51; 1902, p. 92.

N. A. C. LAWSON. The Copper Deposits of the Robinson Mining District, Nevada. Univ. Cal., Dept. Geol., *Bull.,* Vol. IV., 1906, p. 287.

O. J. F. KEMP. Rocks of the Eastern Adirondacks. *Bull. Geol. Soc. Am.,* Vol. VI., 1894, p. 241.

P. C. H. SMYTH, JR. Rocks of the Northwestern Adirondack Region. *Bull. Geol. Soc. Am.,* Vol. VI., 1894, p. 263.

Q. J. E. SPURR AND G. H. GARREY. The Copper Deposits of the Velardeña District, Durango, Mexico. ECON. GEOL., Vol. III., p. 688.

R. M. B. YUNG AND R. S. MCCAFFERY. The Ore Deposits of the San Pedro District, New Mexico. *Trans. A. I. M. E.,* Vol. XXXIII., 1903, p. 350.

S. W. H. WEED. Ore Deposits near Igneous Contacts. *Trans. A. I. M. E.,* Vol. XXXIII., 1903, p. 715.

T. W. LINDGREN, L. C. GRATON AND C. H. GORDON. The Ore Deposits of New Mexico. U. S. G. S., Prof. Paper 68, 1910.

U. E. C. HARDER. The Iron Ores of Western and Central California. U. S. G. S., Bull. 430, 1909, p. 219.

V. W. LINDGREN. The Character and Genesis of Certain Contact-Deposits; Genesis of Ore-Deposits, p. 716.

W. C. K. LEITH AND E. C. HARDER. The Iron Ores of the Iron Springs District, Utah. U. S. G. S., Bull. 338.

X. J. BARRELL. Geology of the Marysville Mining District, Montana. U. S. G. S., Prof. Paper 57, 1907.

SUMMARY OF CRITERIA.

In the following summary is a tabulation of the chief points favoring one or other of the two hypotheses discussed above. The lists are arranged without reference to the special districts from which the various pieces of evidence are taken. A few suggestions are also offered which are in line with the hypothesis of recrystallization. It must be remembered that the use of the term "secondary silicate zone" is in accordance with the interpretation given on page 14.

A. CRITERIA WHICH FAVOR THE FORMATION OF THE "SECONDARY SILICATE ZONES" BY RECRYSTALLIZATION OF IMPURE LIMESTONES.

1. In every case examined, where detailed descriptions of the intruded strata were given, it was noted that there was a plentiful supply of SiO_2, Al_2O_3, Fe_2O_3, scattered through the rock in the way of quartz, kaolin, and limonite, hematite or pyrite, to afford materials for the formation of the silicates.

2. The natural recrystallizations of impure sediments are almost exactly those that are found at intrusive contacts: Sandstones are altered to quartzites. Shales are altered to epidote-amphibole rocks. Limestones (dolomitic) are altered to iron,—garnet and diopside.

3. Al_2O_3 is practically unknown in igneous emanations.

4. The composite straight-line diagram described in the succeeding section shows a constancy of the SiO_2:Al_2O_3:$Fe(Fe_2O_3)$ ratio throughout the change from fresh to altered rock.

5. The composition of an average sample of the rock from the "contact zone" is practically that of a calcareous residual clay (that is, a limestone after the $CaCO_3$ has been dissolved and carried away).

6. The garnet zones, as described by several of the writers, seem to follow the impure beds in the sediments, independently of the contact.

7. If the silicates were formed by infiltration of material, it would seem a very peculiar feature that just those oxides should be added which are almost invariably present as impurities in any limestone horizon.

8. It would also be exceeedingly peculiar that these oxides should be added in the same ratio as that in which they are to be found in the unaltered limestone series.

9. Masses of marble against the intrusive seem capable of explanation only on the recrystallization hypothesis. It is difficult to conceive of hot siliceous vapors being emitted at the contact with one bed and not with another.

10. There is no reason why the garnet zones should fail, as they do very often, just where SiO_2 and Al_2O_3 are wanting in the limestone.

11. Selective metamorphism on a large scale is a prominent feature of these limestone contacts (see page 30, No. 27).

12. Wherever the garnet masses were examined in thin section under the microscope, it was found that the garnet was present in well-defined crystals, many of them idiomorphic with residuary calcite frequently occupying the interstices. In some cases, the crystals showed double refraction probably due to strain. It seems more probable that these crystals should form by a process of recrystallization after elimination of excess constituents, than by pure replacement (in which the structure and texture of the replaced rock are usually preserved) or by infiltration.

13. The reaction-zones of wollastonite, occurring between nodules of chert and the limestone, found by Crosby in the Washington camp, Arizona, are conclusive proof of the formation of at least some of the silicates by recrystallization without infiltration.

14. Lindgren's failure to find fluid inclusions in the quartz grains of the contact zone, although he found them abundantly in

the quartz of the intrusives, is evidence that at least a different origin must be found for the quartz of the contact zone, from that of the quartz of the igneous rocks.

15. The presence of residuary calcite in the interstices of the garnet crystals is difficult of explanation on the hypothesis of infiltration. If SiO_2 was introduced in gaseous or aqueous form, why did it not unite with this lime, that often occurs very close to the contact, rather than pass it by to seek other lime at a greater distance?

16. Recrystallization into marble and silicates obliterates evidences of volume change. Hence the fact that signs of reduction of volume cannot usually be seen does not argue against recrystallization.

17. A comparison of the "secondary silicate zones" around intrusives with the talcose and serpentinous material formed by shearing in the Randville dolomite of the Menominee region[1] is interesting. In the latter case, there has been an elimination of $CaCO_3$, and a recrystallization under great heat and pressure, in the absence of igneous rocks, of dolomitic limestone to silicates. This is almost exactly the same result as occurs at limestone contacts with intrusives.

18. In all cases of contact metamorphism of limestones the substances *apparently* added by the intrusive are silica, alumina, and iron oxide. The metallic and other constituents which are of undoubted magmatic origin vary widely in character and quantity. Sometimes there is iron, sometimes copper, often both. Again there is gold, silver, manganese. Nickel, titanium, beryllium, boron, fluorine, molybdenum, tin, tungsten, tellurium, etc., occur frequently. It seems rather unusual that the typical pneumatolytic constituents should vary so widely from place to place, while the constituents that go to form the "contact-silicates" should be so uniform, if they are all supposed to have the same origin.

19. In most cases, evidence is sufficient to show that without much doubt, there are two stages in the formation of the lime-

[1] U. S. G. S., Mon. 46, p. 221.

stone contact-zones. This favors the recrystallization rather than the infiltration hypothesis.

20. Advocates of the infiltration theory argue that it is preposterous to demand the reduction of volume required according to the recrystallization hypothesis. On the other hand it is just as improbable that there has been an introduction of such a tremendous amount of material from the intrusive, as is required by those who believe in infiltration.

21. In accordance with the theory of crystallization of a magma the volatile constituents and mineralizers are emitted chiefly while the magma is changing from the liquid to the solid form. If a magma be intruded into a series of impure limestones, at a temperature of 1,000°, for instance, is it not likely that great changes will take place in the composition of the invaded rock, while the intrusive is cooling down to the temperature of crystallization? As a matter of fact, it is a very common occurrence to find pegmatite dikes, aplite dikes, quartz veins ("blouts" of Lawson) cutting across the already formed "contact zone" of silicates. In these dikes and veins, the mineralizers of the intrusive are very largely concentrated.

22. The katamorphism of limestones in the southern Appalachians gives a residual clayey material, but is used as iron ore. The percentages of SiO_2, Al_2O_3, Fe in the fresh limestone are in the same ratio as in the ore material.[1] If anamorphosed, these deposits would give secondary silicates with free iron oxide.

B. CRITERIA WHICH FAVOR THE FORMATION OF THE "SECONDARY SILICATE ZONES" BY INFILTRATION OF MATERIAL.

1. In many cases, garnet masses are found entirely apart from limestones, and apparently connected entirely with intrusive igneous rocks.

2. As a general rule, the literature bears out the statement that basic intrusives do not produce nearly as great a contact zone as acidic ones. Acidic magmas or those high in silica are

[1] R. J. Holden, "The Brown Ores of the New River, Cripple Creek District, Va.," U. S. G. S., Bull. 285.

the rocks generally believed to be most richly provided with the so-called mineralizers.[1] It is an interesting coincidence that cold, basic rocks have been found by Rollin Chamberlin[2] to be the richest in gases.

3. The garnet of the contact zones is in the majority of cases the andradite (calcium-iron) variety. This demands a large amount of iron oxide.

4. A very intimate mixture of chalcopyrite with the silicates in some camps indicates a simultaneous crystallization.

5. In many localities in New Mexico, the bedding and locally the fossils are preserved in garnet.

[1] J. F. Kemp, "Contact Deposits"; see "Types of Ore Deposits," H. F. Bain.

[2] R. Chamberlin, "Gases in Rocks," Publication 106, Carnegie Institute of Washington, 1908.

(*To be continued*)

METASOMATISM IN DOWNWARD SULPHIDE ENRICHMENT.

EDSON S. BASTIN.[1]

INTRODUCTION.

The precious metal veins of Gilpin and adjacent portions of Clear Creek and Boulder counties, Colorado, are well known to most mining engineers and geologists, because they were the first precious metal lodes of the state to be developed and still maintain an important industrial position. These veins have been popularly classed as silver veins or gold veins, according as their predominant values were in one precious metal or the other. Field studies in this region by the writer and Mr. J. M. Hill have shown that downward sulphide enrichment is mainly responsible for the workability of the rich silver veins and have shown that the process is mainly restricted to a class of veins showing the following original mineral constituents:

	Metallic.		Gangue.
Principal	Galena. Sphalerite.	Principal	Quartz. Calcite.
Subordinate	Chalcopyrite. Pyrite.	Subordinate	Rhodochrosite. Barite.

As secondary constituents occur, polybasite ($9Ag_2SSb_2S_3$), proustite ($3Ag_2SAs_2S_3$), galena, chalcopyrite, and rarely stephanite ($5Ag_2SSb_2S_3$).

The gold values in the ores from these veins seldom exceed 0.5 oz., but the silver values may reach several hundred ounces.

The consideration of the reasons for the restriction of downward sulphide enrichment to veins of a certain mineralogical type forms the subject of another paper now in preparation; the present paper will be devoted mainly to a description of the

[1] Published with the permission of the Director of the U. S. Geological Survey.

exact mode of occurrence of secondary silver minerals in these ores.

DEPTH OF ENRICHMENT.

Unfortunately most of the mines in which downward sulphide enrichment in silver was a prominent phenomenon, namely those near Lawson in Clear Creek County and Caribou in Boulder County, were opened many years ago, and the rich ore having been worked out, are now idle. Data regarding the original water-level and the relation of the secondary silver minerals thereto was for this reason obtainable only in a few cases. In one of the mines in Gilpin County, the Almaden, there is some indication that the secondary silver sulphides were most abundant shortly below the ground-water level. Regarding the silver mines near Lawson, there is little evidence available upon this point; it is known, however, that in one of the mines of this group that has been opened in recent years (the Little Giant) the original ground-water level was within 60 feet of the surface. This mine, like most of the silver mines near Lawson, is situated on a steep mountain-slope in an area of granitic rocks. It is probable therefore that the original water-level in most of these mines was within 50 or 75 feet of the surface. Downward sulphide enrichment in these veins is an important process to a vertical depth of 500 or 600 feet, and has been recognized in ore from a depth of 700 feet (White vein). It is clear that the ground-water level marks only the upper limit of certain conditions favoring precipitation of silver which continue probably with some modification to very much greater depths. The field studies show that the silver veins of Lawson and Caribou owe their workability almost entirely to downward sulphide enrichment. The original ore from the deeper levels will not pay for extraction under present conditions. A sample of unenriched "steel" galena from the Joe Reynolds vein assayed only 14 ounces of silver per ton. Similar galena from the American Sisters mine assayed only 6.24 ounces of silver and a trace of gold.

MODE OF OCCURRENCE OF THE SECONDARY SULPHIDES.

As already stated the secondary sulphides in this district extend from the ground-water level to depths of at least 700 feet, decreasing in abundance as depth is attained. The sulphides recognized as formed secondarily are galena, chalcopyrite, polybasite, proustite and rarely stephanite. Naturally the secondary galena and chalcopyrite can not always be differentiated from the

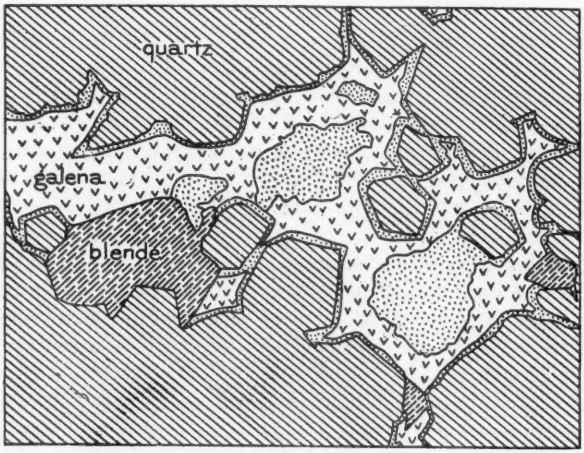


FIG. 5. Camera lucida drawing of a polished surface of ore from Princess of India tunnel, Lawson, Colorado, as seen under the metallographic microscope. The dotted areas show a silver sulphide (polybasite?) developed by metasomatic replacement of quartz and of galena.

primary, but where these minerals encrust crevices or completely fill cracks traversing the original ore minerals their secondary origin is clear. The study of polished specimens of ore under the metallographic microscope shows that the secondary sulphides occur in two ways: (1) As fillings or linings of fractures or vugs in the original vein material, and (2) as metasomatic replacements of original sulphides and quartz of the vein. The

first mode of occurrence has long been recognized and requires no especial discussion here. The second mode of occurrence has not been generally recognized and will be described at more length although full details of occurrence will be reserved for the final report on this district in preparation by the U. S. Geological Survey.

One of the best examples of enrichment by metasomatic replacement is in ore from the Princess of India tunnel, near Lawson. Under the metallographic microscope with relatively low magnification, portions of this ore present the appearance shown in Fig. 5. Between original quartz and galena there has developed a narrow band of a metallic mineral which resembles galena in luster but is somewhat darker gray in color. Larger irregular areas of the same mineral occur within the galena. The mineral upon testing[1] proved to be the silver-antimony sulphide, polybasite. The absence of any bands of polybasite between sphalerite and any of the other minerals is noteworthy. Under higher magnification these borders present the appearance shown in Figs. 6*a* and 6*b*. From these figures it is seen that the bands of polybasite are in places single and in places double. Where the bands are single the polybasite has in some instances replaced quartz, as in the lower part of Fig. 6*b* where the contact between quartz and polybasite is exceedingly ragged, while in other places it has replaced galena, as in the lower part of Fig. 5, where the original crystal faces of the quartz are still intact. Here also the polybasite has replaced larger areas in the interior of the galena mass. Where the bands are double,

[1] Fragments of the mineral were isolated from certain specimens. They were dark-gray, somewhat sectile, reacted before the blowpipe for antimony and when dissolved in HNO_3 reacted with HCl for silver and with NH_4OH for copper. The freshly polished surface has much the appearance of chalcocite under the metallographic microscope, but unlike chalcocite it does not tarnish or etch readily when treated with HNO_3. When treated with concentrated HNO_3 a tarnish begins to appear on this mineral at about the same time that it appears on the chalcopyrite of the ore. When the chalcopyrite shows a faint peacock tarnish the polybasite exhibits a yellowish-brown color in places showing slight iridescence. In specimens where the polybasite is present in too small amounts to be isolated, it may be identified in the polished section by this characteristic behavior with HNO_3.

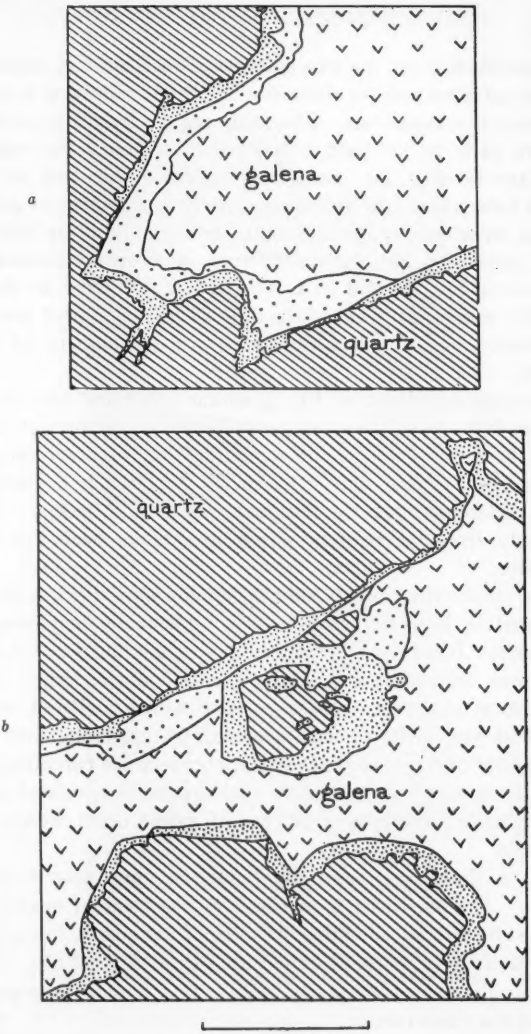


FIG. 6*a* and *b*. Portions of the same specimen shown in Fig. 5, more highly magnified. Dotted portions are a silver sulphide, probably polybasite. Note the double character of the bands of silver sulphide locally. The portions shown by wide-spaced dots have formed by replacement of galena; those shown by close-spaced dots by replacement of quartz.

as shown in Fig. 6*b*, the two portions of the band are separable because of a very slight difference in shade, indicating a slight difference in composition. The fairly regular boundary between the two parts of the band is believed to represent the original boundary between the quartz and galena. One part of the double band appears to have developed by replacement of galena and the other part by replacement of quartz. Both are believed to be polybasite, but slight difference in mineral structure or composition has resulted in a recognizable difference in shade. Probably some constituent of the original galena entered into the composition of the polybasite during the replacement of that mineral.

The sulphides shown in Fig. 5 appear fresh and there is no evidence that any of them represent fillings of fractures or cavities. There seems no way of accounting for the occurrence of the polybasite in this manner except by a molecular or metasomatic replacement of the original quartz and galena. The extremely irregular borders which it exhibits bear out this conclusion.

In a specimen of ore from the Senator mine near Lawson, illustrated in Fig. 7*b*, replacement of galena by polybasite is again seen. It is believed that the whole space illustrated in this figure was originally occupied by galena and sphalerite. The sphalerite as in the previous case has remained unaltered, while the galena has been extensively replaced by polybasite with the development of a very ragged boundary between the two minerals. In this instance a little secondary chalcoyprite is associated with the polybasite. Unreplaced patches of galena occur within the polybasite.

Fig. 7*a* shows ore from the Maude-S. mine near Empire Station. The polybasite is in part a replacement of quartz, as indicated by the ragged outline of some of the quartz, but is also in part a filling in a brecciated portion of the original ore. The specimen illustrates particularly well the total absence of replacement of the sphalerite.

As far as can be judged metasomatic replacement is fully as

important as fracture filling in the sulphide enrichments of the silver veins of this region. That it has not been more generally

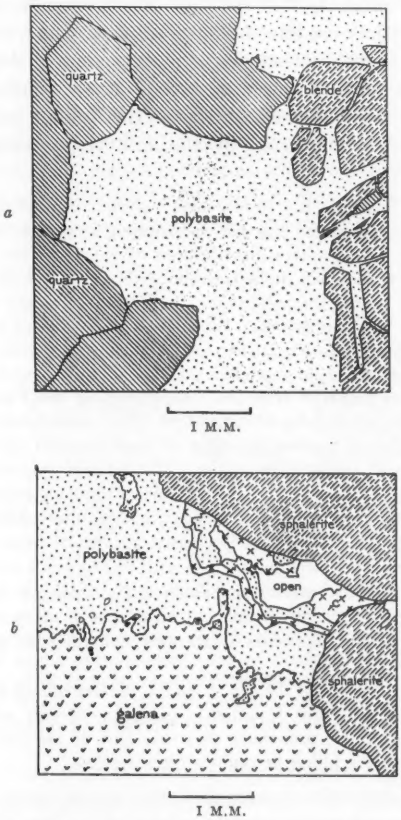


FIG. 7*a* and *b*. Camera lucida drawings from polished sections of ore as seen under the metallographic microscope; *a*, ore from Maude-S. vein near Empire Station, Colorado, showing polybasite in part a replacement of quartz and in part a filling between fragments of original sphalerite which has suffered no replacement. *b*, ore from Senator vein near Lawson, Colorado, showing replacement of galena by polybasite and some chalcopyrite. Note the very irregular borders which sometimes characterize such replacement.

recognized is due to the fact that modern methods of study with the metallographic microscope are essential for its detection. It is altogether probable that the application of such methods of study to rich silver ore elsewhere will show that such metasomatic replacement is the rule and not the exception in deposits that show sulphide enrichment in silver. That such processes have played a part in sulphide enrichment in the Neihart region, Montana, is strongly suggested by the following quotation from Weed.[1]

A specimen from the Big Seven mine "shows ruby silver and polybasite intimately associated together and forming irregular, shreddy, and ragged patches. No positive identification of galena as the nucleus of such masses was made, but the association with galena is such as to indicate a possible change to polybasite. . . . The blende seen in another section of such rich ore is invariably surrounded by a dark crust which is not iron oxide, nor does it appear to be an iron-rich blende. It is not definitely determinable, but resembles galena or a silver sulphide. . . .

"The material gathered from the lowest level of the Florence mine shows polybasite in the form of crystalline tablets upon barite and other minerals, and also as a moss-like mass of open skeleton texture which seems to represent arrested deposition. The latter form is believed to come from a place in the vein where mineral-bearing water is now depositing this mineral, together with spar, quartz, and probably galena. Studied under the microscope the polybasite appears to be an alteration product of galena, and itself to be mixed with and to grade into pyrargyrite, which is in some cases its undoubted alteration product. It is certain that polybasite, as the important constituent of many of the ores, is of secondary origin. It occurs on all other minerals, and is itself not coated or dotted by them.

"Thin sections show that the barite seen in the ore occurs in fractures of the original spar. Such fractures, cutting across spar crystals and shattering pyrite grains, sometimes show one part of the fracture filled by barite, with quartz filling beyond on the same line."

To test the suggestion conveyed by this description a specimen of rich silver ore from the 300-foot level of the Big Seven mine found in Weed's collection in the U. S. National Museum (No. 53,643, U. S. N. M.) was polished and studied microscopically.

[1] Weed and Pirsson, "Geology of the Little Belt Mountains, Mont.," Twentieth Ann. Rept. U. S. Geol. Survey, Pt. 3, 1900, pp. 411–412.

This specimen shows an ore consisting principally of galena, chalcopyrite, sphalerite, barite, dark gray quartz, and a brown carbonate, all apparently contemporaneous and original. One side of the specimen represents the wall of an open fissure and along this side a coating of polybasite and pyrargyrite up to one fourth inch thick has been deposited with the development of very perfect crystal faces on the polybasite. With these is associated crystalline quartz. The two silver sulphides and the quartz appear essentially contemporaneous and are plainly a secondary coating along a fracture in the original ore. In addition to this, however, portions of the original galena adjacent to the open

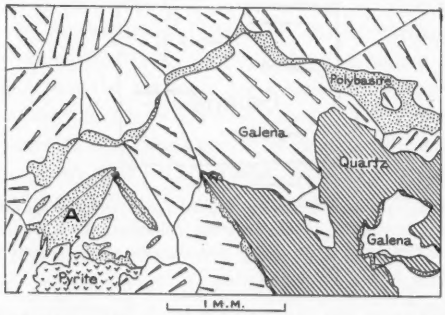


FIG. 8*a*. Polished surface of ore from the 300-foot level of the Big Seven mine, Neihart, Montana. Shows metasomatic replacement of galena by polybasite following the contact between galena and quartz and between different crystals of galena and following cleavage cracks in the galena. Areas of galena are white or show characteristic triangular pits. Dotted areas are polybasite. The area marked *A* illustrates replacement working outward from a cleavage crack which can still be distinguished.

fracture have been metasomatically replaced by polybasite in a manner analogous to that observed in the Colorado ores just described. The replacement is initiated at the contact between quartz and galena, between two crystals of galena, or along cleavage planes within the galena, all of these relations being illustrated in Fig. 8*a*. Such contact and cleavages evidently were planes along which the replacing solutions could gain access

although the openings were so minute that they appear as mere lines even under several hundred diameters magnification. Where the replacement has followed a cleavage direction the area of polybasite is commonly spindle-shaped in outline, as shown in

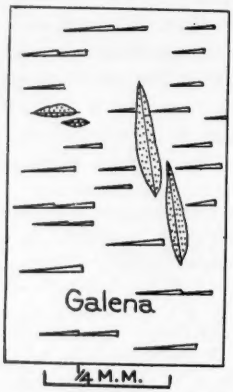


FIG. 8*b*. Portion of another galena crystal from the same specimen as Fig. 8*a*, more highly magnified and also showing replacement by polybasite working outward from cleavage cracks. Note that the two smaller lenses lie parallel to the triangular pits of the galena surface.

Fig. 8*b*, and the original position of the cleavage plane is still marked by a line extending from end to end of the polybasite area. The cleavage crack is not usually recognizable beyond the replaced area.

The only published account of metasomatic replacement similar to that described above that has come to the writer's attention is a description by Fenner[1] of a specimen forwarded to the Columbia School of Mines from Leadville. Its mode of geologic occurrence is not known. The specimen is a rhyolite porphyry in which the groundmass has been wholly or partly replaced by stephanite and chalcopyrite. In certain parts of the

[1] Fenner, Clarence N., "A Replacement of Rhyolite Porphyry by Stephanite and Chalcopyrite at Leadville," *School of Mines Quarterly*, Vol. 31, 1910, pp. 235–240.

specimen it is possible that original pyrite has been replaced by secondary chalcopyrite.

NATURE OF THE REPLACEMENT.

It is significant that the replacement of original minerals in the solid ore has involved neither contraction, expansion, nor the development of porosity. This fact is particularly well shown in Fig. 8*b*. As pointed out by Lindgren,[1] such constancy of volume shows that the replacement can not be regarded as a substitution of a given number of molecules of polybasite for the chemically equivalent number of molecules of quartz or galena.

Not only is the metasomatic replacement in these veins most extensive in the vicinity of relatively large fractures but the secondary minerals developed by such replacement and those which fill or coat the fractures are identical in character and in many cases *may be traced continuously into each other.* These relations indicate that deposition in previously formed fractures and deposition by metasomatic replacement were going on at the same time, presumably through the agency of the same mine water, and deposited the same minerals. It seems necessary to conclude that in the cases here described the two methods of enrichment are merely different expressions of a single process. The mineral dissolved is unstable under the particular existing conditions of temperature, pressure, and nature of mine water; the replacing mineral is stable under these conditions and is therefore deposited. If open fractures are present for its reception it will deposit in them, but in unfractured portions of the ore its deposition must wait upon the removal of other material.

Electrolytic action, which Gottschalk and Buehler[2] regard as an important factor in the solution of sulphides in the oxidized zone, appears to play no important part in the phenomena here described, as is shown by the replacement of quartz, a very poor conductor, and by the fact that replacement is not confined to the

[1] Lindgren, W., "The Nature of Replacement," ECON. GEOL., Vol. 7, pp. 534–535.

[2] "Oxidation of Sulphides," ECON. GEOL., Vol. 7, 1912, pp. 15–34.

contact between different minerals but occurs within single crystals of galena (see Fig. 8*b*).

To the writer the fact that *most metasomatic replacements are accomplished by circulating solutions whose supply of replacing material is constantly being renewed,* appears to be of fundamental importance. Such phenomena can not be interpreted according to the same rules that govern the interaction of solids and solutions in a chemist's test tube. If we place in a test tube full of acid a fragment of some mineral that the acid will attack, chemical action will continue until a condition of equilibrium is reached. Equivalent weights are involved in any chemical interchange that takes place, *i. e.,* the reactions are metathetical. The processes may be expressed by chemical formulæ. The conditions under which replacement takes place in nature differ from those just described in the fact that the solutions are circulating and that at any particular point where replacement is in progress the material dissolved is being constantly carried onward while fresh supplies of the replacing material are constantly coming in. With ascending thermal solutions furnishing in hydrothermal metamorphism a continual supply of replacing material and solutions from a constantly sinking oxidized zone performing the same function in the case of downward sulphide enrichment, the development of chemical equilibrium may be indefinitely postponed. With such circulating solutions therefore, chemical balance at any particular point where replacement is in progress becomes not only an unnecessary but an impossible assumption. The process is not metathetical and the volume relations between the replaced and replacing minerals cease to be significant.

Most waters when in contact with a variety of minerals are taking certain materials into solution while depositing certain others, and this is particularly the case with mine waters. The failure to develop a porous structure during metasomatic replacement obviously means that the solution was capable of depositing certain minerals in such quantities that they could immediately fill all of the open spaces formed by the solution of other

minerals. In the cases described in this paper there was a tendency to deposit in *all* open spaces as shown by the filling or coating of fractures by secondary minerals coincident with their deposition in the solid ore through metasomatic replacement. It is obvious that in those specimens where the secondary sulphides deposited in fractures can be traced continuously into similar sulphides formed by metasomatic replacement, some of the secondary sulphides between those that lie well within the solid ore and those that line the open fractures must have developed by replacement in a situation where freedom of movement was possible. If freedom of movement is the factor which conditions the development of porosity during metasomatic replacement it would seem that such parts of the ore should show porosity. On the contrary no porosity is developed.

The development of porosity during metasomatic replacement appears in most cases to mean simply that the solution was able to dissolve certain minerals more rapidly than it could deposit an equal volume of other minerals in their place. Replacement with development of porosity is particularly characteristic of the processes of rock weathering and the gossan alterations of veins.

SUMMARY.

1. Metasomatic replacement is shown to be an important process in downward sulphide enrichment in certain veins.

2. No change in volume is involved in the replacement.

3. The secondary minerals deposited in fractures are identical in character and often crystallographically continuous with those deposited by metasomatic replacement and are probably different expressions of the same general process.

4. Since the solutions which accomplish the replacement are circulating and their supply of replacing material is constantly being renewed, the replacement process can not be metathetical in character and no constant relationship between the volume of the replaced and replacing minerals is to be expected.

5. Whether or not porosity develops during replacement appears to depend mainly upon the ratio between the dissolving and depositing tendencies in the solutions.

EDITORIAL[1]

WITH the recent wide recognition of the necessity for geological investigation in reports on mining properties and the development of working mines, published geological reports have become widely read and utilized. There are few engineers or geologists who have not had frequent recourse to the reports of the U. S. Geological Survey and it is probable that much of their work would have offered greater difficulties had these publications not been available. A great deal of geological work, however, is carried on by engineers in regions where no literature is available or where more detailed work than the U. S. Survey is able to attempt becomes imperative. Field work must then be conducted without the assistance furnished by published geological work or with only broad geological conclusions as a foundation. In such cases a knowledge of the details of field work becomes a matter of very great importance and it is greatly to be desired that the most effective methods should be readily at the disposal of all who need them. That the engineer whose attention has generally been directed to purely commercial questions should find his early and often scanty training in field geology adequate, especially when much that he has learned in former years has long been superseded by the more accurate and rapid methods of modern practice, is scarcely probable. Several admirable books on field methods are available but they are in part elementary and therefore somewhat inadequate. The published reports of the U. S. Survey offer but scanty information or none at all of the methods by means of which the results have been attained.

The professional geologist does not, of course, feel the need of an exposition of methods to so great a degree, but the new devices

[1] The signed editorials which it is designed to publish from time to time in these columns are expressions of individual views and do not represent the consensus of opinion of the editorial board.

which other men develop will often, if presented to him, offer suggestions of very great value.

The attention of the readers of ECONOMIC GEOLOGY is therefore directed to the discussion on field methods which begins with the current issue. It is earnestly hoped that all geologists and engineers will alike contribute either outlines of ordinary geologic methods which, though commonly used in practice, will bear a wider publication, suggestions as to new methods, or statements of problems for the solution of which no field methods are generally known. Methods for the compilation of notes in the office interpretation of geologic data will also be of great interest.

It too often happens that to those who devise new methods long use and familiarity has made them seem unimportant and scarcely worthy of presentation, but to others who have been occupied with different problems or do not devote all of their time to the geological side of mine examination, such methods may be wholly unfamiliar and if presented where they are readily available will serve to save much unnecessary labor. Simple and apparently unimportant details in which there may seem to the originator nothing especially new or noteworthy are often of great value, and the eagerness with which they are received comes frequently as a surprise to those who have devised them.

We may therefore hope that all geologists, with whatever work they may be occupied, will endeavor to add something to this discussion.

J. D. IRVING.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE SUB-STRUCTURE OF GEOLOGICAL REPORTS.

The results of geologic work as presented in geological reports are known to many; the methods by which these results have been attained to comparatively few; furthermore, it frequently happens that only the simpler and more basic methods of one worker are commonly known to and used by another. The details, innovations, short cuts, and systems for attaining greater speed and accuracy which are developed by one will be different from those in use by another.

A comprehensive discussion of field methods would, therefore, afford a sort of geological clearing house by means of which each worker might be enabled to improve his own methods of work and at the same time perform a similar service to others. In addition to this, those to whom geological field work is merely an aid in making estimation of the value of mining properties might find it possible to utilize some of the methods suggested by geologists who are continually employed in geological work.

Several books have recently been issued, notably that by Dr. C. W. Hayes, which have done much to assist geologists in their field work and to acquaint those in other lines of work with many of the methods in use by the U. S. Survey, but it seems probable that there is much to be added to this, and that the last word has by no means been said as to geological field work.

In starting the present discussion, therefore, it is my purpose to outline briefly the various steps in the preparation of a geological report, without entering into elaborate description of any particular method; not because such a summary can lay claim to anything of novelty, but because it may serve to call to the minds of those who can make contributions the particular steps in geological work to which they may be able most readily to contribute something of importance. I am aware that in presenting this outline I deal with generalities familiar to all and risk the criticism of a didactic statement of all too obvious facts, but if it serve to call forth detailed expositions of method it will be in a measure justified.

Conversation with many geologists has convinced me that there is a wealth of unpublished material whose presentation would be of material value, but which is withheld by the undue modesty of those who are able and alone able to present it to others. Geology is passing rapidly from the qualitative stage into one which is essentially quantitative, where accuracy above all things is a *sine qua non* and where the validity of conclusions and their practical application are rapidly gaining recognition. It is believed that if geologists are willing to take the time to contribute liberally to this discussion it may be of very great assistance to all workers.

STEPS IN THE PREPARATION OF A GEOLOGIC REPORT.

The work which forms the basis of a good report on the geology of any area of country, for whatever reasons the study be made, cannot be intelligently discussed unless the reader has before him a classification of the different steps into which such work naturally falls. This can best be presented in tabular form. In order that what follows may be more clearly comprehended, the following tabular outline is therefore offered.

PREPARATION FOR THE FIELD.

1. Securing of all available information on the region to be studied.
2. Choice of equipment.

ACTUAL FIELD WORK.

1. Reconnaissance—surrounding the problem.
   (*a*) Complexity of metal mining districts.
2. Gathering field impressions.
   (*a*) Relative value of field thought and office thought.
   (*b*) Method of retaining field impressions.
3. Collection of records.
   (*a*) General.
      (1) Intelligibility.
      (2) Accessibility.
      (3) Completeness.

      The Elements of Geologic Records.

   (*b*) Location of points at which data are collected—field measurements.
   (*c*) What to record.
      (1) Adaptation of records to special problem involved.
      (2) Necessity for recording determinative criteria.
      (3) Determination of the cartographic unit.
      (4) Indication of geologic boundaries.
      (5) Observations within areas between boundaries.
   (*d*) Where to record.
      (1) General—mental records. Relative extent to which map and note-book should be used.
      (2) Cross-reference methods.
   (*e*) How to record.
      (1) Choice of method.
      (2) Fitting the geological surface to topographic relief.
         i. The nature of geologic surfaces.
         ii. Adjustment to topographic relief.
      (3) Methods of record in use for surface geology.
         (α) Boundary tracing methods.
            i. Pencil crayon method.
         (β) Cross traverse methods.
            i. Letter traverse method.
            ii. Profile traverse method.
         (γ) Multiple outcrop method.
      (4) Methods in use for underground work.
4. Collection of material.
   (*a*) What to collect.
   (*b*) Cataloguing and cross-referencing of collections.

PREPARATION OF REPORT FROM COLLECTED DATA.

1. Preparation of surface map.
2. Construction of geologic sections.
   (*a*) Choice of section lines.
   (*b*) Checking of intersecting sections.
   (*c*) Methods for plotting faults and boundaries.
   (*d*) Symbols for representation of rocks.
3. Construction, use, and value of stereograms.
4. Interpretation of geologic records and collections.
   (*a*) The use of analyses and assays.
      (1) Methods of recalculation.
5. Writing the geologic report.

The three main divisions of work—Preparation for the Field, Actual Field Work, and Preparation of the Report—are intimately dependent on each other and no one of them can be successfully slighted.

The failure to gain satisfactory results can always be traced to a neglect of one of the three and often to those simpler and apparently insignificant things that hardly seem worthy of consideration. Thus, a neglect of proper preparation for the field brings the geologist to the problem without the proper equipment to meet the conditions; failure to examine the literature of the region makes it necessary to measure extensive geological sections which have been worked out in very great detail by earlier workers—sections which require much labor and time, and without which structure cannot be deciphered; the inaccurate recording of notes in the field or the adoption of complex and unintelligible field methods renders the field work valueless and the compilation of a correct report an impossibility; and finally, however accurate and skillful field work may be, and however clearly and intelligibly it may be recorded and interpreted, it can have little or no value if presented in an unconvincing manner.

There are skillful geologists, far sighted in preparation, quick in observation, keen in judgment, conscientious and accurate in recording data, who are unable to write a geological report. Their failure is no less a failure because their work and conclusions are correct—the ability to present clearly, and above all

convincingly, is equally vital and cannot be neglected any more than either of the other branches of work.

PREPARATION FOR THE FIELD.

General.—Concerning the preparation for the field, little may be stated that will not readily occur to those who are accustomed to any variety of field work, whether it have for its object commercial or scientific results. It may not, however, be amiss to indicate briefly in what manner labor may be saved and waste of valuable time avoided.

Field seasons in most instances will be found too short for the accomplishment of all that may be desired. This is particularly true in northern regions like Alaska where the conditions permitting out-of-door work do not allow geologists to continue in the field for more than a brief period of time. In any case, all the time which can possibly be saved either by adequate preparation before taking the field or by shortening the operations which properly constitute field work will materially increase the amount and hence the value of the data which are collected.

1. *Securing Information on the Region to be Studied.*—It rarely, if ever, happens that the geologist is called upon to visit a region upon which no information of *any* kind can be secured. It will generally be possible for him to find either published data on the country or if not that to secure from others who have visited it verbal information as to the conditions under which work may be done. By the exercise of foresight in securing all such information he will frequently be able to reduce the amount of equipment taken, plan the geologic work so as to accomplish it in the shortest possible time, and insure his efficiency and comfort under the climatic conditions which may be encountered. Information of this kind may relate to the following different questions:

1. Climatic conditions.
2. Number and character of the routes of travel within the region to be studied.
3. Topographic relief.

4. Available water supply.
5. Character and density of vegetation.
6. Facilities for travel.
7. Distribution and accessibility of bases of supplies.
8. Character of available base maps.
9. Amount of development if a mining district.
10. Attitude of mine owners.
11. Nature of the geologic problem to be studied.

It is scarcely necessary to discuss the modifications in plans of work and equipment which will result from a consideration of accurate information on these various questions. Suffice to say that *climatic conditions* will affect clothing, camp equipment, the nature of paper used for field maps and note books, cases for the protection of instruments, etc.; *available routes of travel* will affect methods of field work, number of assistants needed, portability of equipment of all sorts, methods of tieing surface work to lines of travel on map, extent and character of exposures to be expected, necessary funds for financing the work, and nearly all phases of the work; *topographic conditions* will affect instruments and note books used and systems of traverse; *accessibility of bases of supplies* will determine whether camp outfits are necessary or not; *facilities for travel,* whether horses, canoes, steam launches, railways, trolleys, handcars, or foot work will be the rule; *available base maps* will often determine whether work is possible at all without the preparation of a topographic map, and if available, the accuracy and the amount of culture shown will establish the methods of survey used; *vegetation* will often decide field methods; *amount of development,* whether mine maps are available and a pantograph needed; *the attitude of mining men,* whether underground work will be possible; and finally, *information on the geology* will determine what methods of survey are necessary, things to be determined in field work, relative importance of vertical and horizontal measurements, and will affect nearly all the problems involved in the work. Lastly, *the care with which the geological information is studied* will often result in the elimination of a vast amount of work in reconnaissance and the laborious measurement of stratigraphic sections.

Under such circumstances it will be only the exceptional geologist who will think it well to leave the preparation for the field to the last minute and any devices by means of which such preparation can be made more effective and valuable will be of great importance.

2. *Choice of Equipment.*—As just stated, the choice of equipment will depend in part upon all of the different phases of information secured, but it will be perhaps more especially dependent on the nature of the geologic problem. Instruments, paper, maps, books, outfit for collecting specimens, and all other impedimenta carried by a geologist for his field work vary according to the nature of the problem approached. For regions in which igneous rocks constitute the main feature, one equipment will be necessary; in regions where stratigraphic rocks slightly folded occur, an entirely different equipment will be required. In regions of highly inclined or vertical rocks, horizontal distances are of preeminent importance, and special care must be given to instruments necessary for the measurement of such distances. Where strata are flat and low-lying, vertical distances are important and horizontal distances are comparatively negligible. The barometer, the *Y* level, and other means for measuring vertical distances will then become of corresponding importance. The equipment chosen, therefore, will be in large measure dependent upon the character of the geology as learned from a careful study of available literature.

The scale of the final map will also be of importance in selecting equipment, as the relative limits of permissible error will determine what kind of instruments are necessary for measurements of distance and the location of points.

An ingenious scheme was suggested to the writer some time ago by which some of the labor usually incident to the preparation of equipment for the field might be lessened. On the inside of the lid of the trunk designed to contain field equipment was attached a separate detailed list of all of the material needed to meet the conditions in each type of region. It was then only necessary to indicate to an assistant which set of material was

required, and the necessary equipment was at once packed. It was unncessary for the geologist to go over each time a careful study of the material necessary.

ACTUAL FIELD WORK.

Except in those rare cases where reports may be actually written and completed in the field, field work is confined to the collection of data and specimens and to the construction of maps and sections. Work of this kind will fall readily into the following divisions:

1. Reconnaissance—surrounding the problem.
2. Collection of field impressions.
3. Collection of records.
4. Collection of material.

1. RECONNAISSANCE—SURROUNDING THE PROBLEM.

(*a*) *Complexity of Mining Districts.*—Geological structure and the broader relations of geological formations within any given area are but small portions of more extended problems. To grasp fully the geology of any district, therefore, its relationships to larger areas of which it is a part must first be investigated. This is particularly true of mining districts. Ore deposits usually occur in that part of a given area where the structure and interrelationships of the rock formations attain their maximum complexity. The very existence of ore implies extensive fracturing of rocks, varied igneous intrusion, intense alteration of rocks, and the more or less complete masking of their original character. The key to the problem, therefore, usually lies in the surrounding country and is often to be found at a considerable distance from the ore deposits themselves. For this reason it is almost imperative that the geology of the outlying country to a considerable distance from the ore deposits should first be studied. Each formation can then be measured, its prevailing characteristics noted, and its lithology understood before it is followed inward to that portion of the area where the deposits

themselves are located. If this be done, rock formations that are altered beyond recognition near the mines may be so well known and understood that the gradual increase in alteration which occurs when they are followed inward may be easily appreciated and the original character of the formation will offer no special difficulty. In many cases problems that seem almost unsolvable become surprisingly clear in the light of the knowledge thus gained.

It too often happens that the reverse method of procedure is pursued. Geologists go first to the deposit, study the ores as they occur underground, frequently neglecting not only a reconnaissance of the outlying country but omitting surface work entirely, and are usually in the dark both literally and geologically.

2. FIELD IMPRESSIONS.

(*a*) *Relative Value of Office and Field Conclusions.*—No matter how careful a geologist is to make his notes complete and intelligible, there will almost invariably be portions of them (and usually the most important portions) which he will fail to understand after his return to the office. The impossibility of checking up observations when he is so far removed from the field will make it necessary that he should make the best of the material which he has. It is then that he feels most strongly the value of those impressions which he gathered during his actual work in the field. A geologist who confines his attention entirely to the collection of records and neglects to stop and endeavor to think out his problem finds it much more difficult to think out when he reaches the office. Thought devoted to the problem when actually on the ground often yields extremely valuable suggestions. Time should not only be taken for gaining such impressions in the field, but they should be carefully and clearly written out in one's note books. In his little and very entertaining book on "Field Geology," Sir Archibald Geikie emphasizes this point by saying that it is very important for a geologist at the close of every day to sit down and write out his notes, field impressions, etc.; that he should do this remorselessly, no

matter how seductive his after-dinner cigar or his evening companions, or his evening paper might prove to be.

It frequently happens that in the rapid preliminary examination of a mine, when the geologist is being shown about the workings by some foreman or superintendent, there is but little opportunity to stop sufficiently long to take adequate notes; also in going about the country rapidly to stop and take detailed notes often interferes with one's getting a comprehensive grasp of the problem. Under such circumstances, it is possible to adopt a system by means of which the notes can be written out with very considerable accuracy after one has returned from the field in the evening. A series of simple headings may be put in one's note book, for instance, as given below:

Fault breccia in southwest stope.
Banding of ore on first level near shaft.
Possible origin of mineralization suggested by cross fractures on third level at Raise 22.
Uniform southwest dip of strata in mine. Reasons for.

After one has come out of the mine with these few simple headings which it takes but a second to record, he will be able to sit down and with them as a reminder write in clear and intelligible English a description of his trip through the property.

3. COLLECTION OF RECORDS.

(*a*) *Intelligibility.*—The first prerequisite of any set of records is that they should be intelligible. No system of recording notes which cannot be understood after a few months' time has elapsed is of any service. It is a practice with certain workers to adopt some cryptic method for the taking of notes, so that they will be unintelligible to others than themselves. The difficulty with such cabalistic systems is that they soon become unintelligible to the authors. In other cases records are kept without method, or the key to the system employed is omitted in the notes, so that the results of much labor and expense are rendered valueless. As an illustration of this, an instance may be worthy of mention. A profile section across country was being made by the assistant to a

certain geologist and the character of the various rocks traversed was recorded from time to time on the running profile. In order to shorten time for record, the abbreviations "S.S." for "Sandstone," and "L.S." for "Limestone," with appropriate symbols indicating dips, were recorded. In working up the results the chief geologist found the constantly recurring but wholly unintelligible symbol "F.R." After some search the assistant was found and volunteered the information that "F.R." signified "Funny Rock." The incident would be more amusing if it had fewer analogies.

(*b*) *Accessibility.*—So far as possible during field work, notes should be confined to the smallest number of note books and maps practicable. One of the most fruitful causes for delay in office work is the constant and recurrent search through multitudes of maps and note books for certain recorded data which the geologist knows must be somewhere but cannot recall just where. Mine maps should, whenever possible, be combined on a single working map and all geological data recorded or transferred in the field to that map. In the later work in the office, that map alone need be consulted and much time and nerve-destroying search for records avoided. The writer is at present engaged upon the compilation of a report covering some twenty years of field work by four or five different geologists, and constant search for data through 64 note-books and more than 1,000 mine maps enables him to speak authoritatively on this point.

(*c*) *Completeness.*—One of the unfortunate delusions from which few geologists are immune is that of the additional information which they will obtain when they make a second visit to some especially interesting and important locality. If the problem upon which a geologist is working is complicated, he frequently feels that it will be impossible for him to gather the necessary data in a single visit; that there is too much to be seen there for him to get what is necessary during the time available in that particular visit; that he had better simply look the problem over and then later return and make more elaborate and careful notes. He never does return. The data collected while

he was on the site are in almost every instance all which he has to show. The notes and collections which are made at any point ought to be made as complete as possible *during the first visit,* for the first time the geologist visits that spot is likely to be also the last.

THE ELEMENTS OF GEOLOGIC RECORDS.

To record satisfactorily observations in the field, the geologist unconsciously answers four questions:

1. Where is the locality concerning which the record is made?
2. What is to be recorded?
3. Where is the record to be made?
4. How is the record to be made?

These four questions are briefly answered in outline with the hope that geologists may contribute to the discussion detailed statements of the several features indicated.

(*b*) LOCATION OF POINTS AT WHICH DATA IS COLLECTED.

Field Measurements.—In order that data may be recorded on surface maps and mine maps, or written notes properly referred to the locality with which they deal, the locality itself must be accurately determined. To determine points upon a map some method of survey must be employed and in these later days when greater accuracy of detail is required of the geologist too great care cannot be taken in such determinations.

Any method of survey employed involves measurements, and the accuracy of the work will depend upon the instruments or methods by means of which the measurements are made.

All field measurements need not be made with equal accuracy. The limits of error permissible depend upon the scale of the map. Thus on a map of the scale of a mile to an inch, a measurement to the nearest ten feet would locate a point much closer than the minutest possible width of a line, and a method ensuring such accuracy would be wholly unjustified. Conversely on a map of the scale of 100 feet to one inch a measurement only to the nearest ten feet would involve a glaring error. In like manner, if

a geologic boundary, owing, say, to insufficiency of outcrops, can be located no nearer than the nearest 100 feet, measurements by transit are a criminal waste of time. Methods for the determination of the permissible limits of error are readily learned, but it is my hope to secure a paper on this subject as a contribution to this discussion, so that it need not be further mentioned here.

Field measurements are of four kinds:

1. Measurements of horizontal distance.
2. Measurements of vertical distances.
3. Angular measurements.
   Azimuth measurements.
   Dip measurements.
4. Measurements of the thickness of strata.

Into all of the methods of recording data in note books and on maps these different methods of measurement enter, and the various methods of work later outlined may be made more or less accurate as the scale of the map requires according to the instrument employed. The following are some methods of measurement arranged in the order of increasing accuracy.

1. *For horizontal distance:* Foot pacing, horse pacing, wheel revolutions, by cyclometer or counting, planetable (or transit) and stadia, or accurate taping.

2. *For vertical distances:* By barometer, handlevel, triangulation, or *Y* level.

3. *For angular measurements:* By compass, planetable, or transit.

The further discussion of Field Measurements is left to contributors.

(*c*) WHAT TO RECORD.

1. *Adaptation to Special Problems.*—The data which it is necessary to record will differ according to whether field work is directed toward the study of:

1. Igneous rocks,
2. Sedimentary rocks,
3. Metamorphic rocks,
4. Ore deposits,

5. Coal deposits,
6. Oil and gas deposits,
7. Glacial geology.
8. Structural features.

In his admirable little book on "Field Geology," Hayes[1] has indicated the various observations which it is important to make in dealing with each of these special features, and it is perhaps unnecessary to repeat all of them here. I believe that much, however, remains to be said in regard to all of them which the small compass of his book did not permit. I am possibly not too sanguine in hoping that some geologist especially familiar with each special feature will contribute a discussion of the nature of the observations that are particularly important.

2. *Necessity for Recording Determinative Criteria in the Study of Ore Deposits.*—In nearly all geologic work the data recorded are of two sharply distinct types: (1) data which are essentially descriptive, and (2) data which assist in the determination of the problems of origin. This is especially true with regard to ore deposits.

As illustrations of descriptive data, the following may be cited: *records of production, nature and character of ores, extent, form, and geologic occurrences of ores, amount of development, grade, and value of ores, methods of mining and treatment, relations to enclosing rocks,* and a large array of more or less easily observed and recorded features which properly belong in a full and comprehensive description of any deposit. There are many geologists who are keen observers of such features, who are able to collect them conscientiously, and to work them up into excellent descriptive reports, but fail to draw from their study correct conclusions as to the origin of the ores.

Origin is a question which overshadows all others in scientific importance, and now admittedly also in the assistance which it furnishes in development, prospecting, and other phases of purely practical work. For correct conclusions as to origin, observations must not only be comprehensive, they must also be *determinative.*

[1] "Handbook for Field Geologists," pp. 86–148.

No geologist collecting descriptive data at random, or with a purely descriptive report in mind during field work, can successfully secure determinative criteria on origin. The desire to obtain them must be *conscious* and it cannot be so unless the problem be approached with a carefully thought out set of criteria upon which the final conclusions are to be based. This is the reason why some geologists can secure in a short visit conclusive data and write phenomenally able papers where others have spent years of labor without satisfactory results. This is why the oft-reiterated criticism made by conscientious workers who have spent long periods in futile effort of those who, they complain, "pretend to secure conclusive evidence in a few days or weeks" is frequently so bitter and lacks so much of justice.

The geologist who attacks the problem with a clear conception of the essential *diagnostic criteria* strikes at once at the heart of the problem and the frequently reliable quality of his deductions in itself offers a silent criticism of less able workers which may well embitter them.

Too much could, in my opinion, scarcely be written on this important feature, and *geological diagnosis* might well be elevated into a special branch of geologic work. One of the difficulties of approaching the problem with clear ideas on this subject is the paucity of published work setting forth necessary criteria. Simple knowledge of the geologic occurrence and opposing theories of origin of a deposit is not sufficient. Purely descriptive data must be mentally relegated to a separate phase of the work and special efforts made to eliminate from the work on diagnosis all features which are not important to the end in view. It is to be hoped that the especially important criteria may be more frequently set forth in future text-books than in past years. As an illustration, a few of the criteria which may be applied to deposits of magnetic iron ore may here be tentatively cited.

Diagnosis of Possible Magmatic Segregations.

1. External Criteria.

Is the ore related to an eruptive mass?

Is the eruptive the kind usually associated with this particular oxidic mineral?
How related?
Is the position of the ore peripheral?
Does it fade into country rock?

2. Internal Criteria.
Mineralogical:
Does it consist of minerals which are typical of the main body of the eruptive mass, or is it a mineral that occurs only in the ore mass?
Are any of its component minerals distinctly igneous?
Does it contain any non-igneous minerals, such as fluorite, tourmaline, chalcedony? (This can be applied only if it is unmetamorphosed.)
Textural:
Are the microscopic relations of the sparsely disseminated grains in the lean ore such as show it to be an early crystallization?
Has the massive ore eutectic structure?

3. Relation to Regional Metamorphism.
Has the deposit been metamorphosed, or was it formed before metamorphism?
What is the evidence of metamorphism? Is the ore schistose or gneissic? Are the ore minerals earlier or later than the regional metamorphic minerals? (Especially red garnet and uralite.)

4. Is the ore associated with contact metamorphic minerals?
Is it intergrown with such minerals so as to show contemporaneous origin?

5. Does it contain *angular,* unsupported inclusions of country rock?

I do not maintain that these particular criteria are either complete or conclusive; they are hastily set together merely as an illustration.

Indications are not lacking that published literature is to contain more and more practically useful criteria—the volume about to be published by the U. S. Geological Survey on secondary sulphide enrichment is a case in point—but even now a little careful thought will often enable a worker to establish a fairly reliable group for himself. I only wish to urge here that this should be done *before* attacking the problem and that the effort to make *selective* observations should be at all times a *conscious* effort.

3. *Determination of the Cartographic Unit.*—In making a geological map, the first question to be decided is what to indicate on the map. To each formation or rock group indicated on a map the name "cartographic unit" is usually given. In order that a cartographic unit may be mapped and the area within which it is exposed correctly indicated, a decision must first be made as to where the dividing line between the several units will come. In other words, the limits of the geological formations which it is desired to show must be determined before they can be indicated. In dealing with igneous rocks, it is often comparatively easy to make distinctions between the different types as they will be generally of different ages and their outlines easily determined. Much discussion has taken place as to what may properly be considered a cartographic unit. A symposium was held by the geologists of the U. S. Survey some years ago on this subject and a set of tentative rules established for the use of the Survey. A paper dealing with such criteria would add much to the present discussion.

4. *Indication of Geologic Boundaries.*—When the formations which it is intended to indicate on the map have been decided upon, the mapping work will divide itself into two parts.

1. The indication upon the map of the lines of demarcation, or "geological boundaries" between the several formations.

2. The indication of structural and other characteristics observed within the area of any single formation.

Of all of the data which need to be recorded, the geologic boundary is the most far-reaching in importance and is the feature about which most has been said in books on field geology. Once a geologic boundary has been accurately indicated on the map, it serves as a key (and in the absence of sections generally the only key) to structure, indicates the form and often the origin of igneous masses, the relative ages of intrusives, and in many other ways furnishes the keystone to the geologic problem. Its correct and accurate mapping is therefore justly given the preeminence among data that need to be recorded.

Boundaries should, therefore, be determined with scrupulous care and their position accurately fitted to the topography. This may be done with greater or less accuracy according to the methods of survey used in determining its location and the number of points which are determined. Boundaries are sometimes obscured and covered with débris, and cannot therefore be accurately located. The method of survey used to locate them need be only slightly more accurate than the limits within which they may be observed. It is, for instance, undesirable to use a method of survey accurate to the nearest ten feet to determine a boundary whose actual position cannot be determined closer than the nearest 500 feet.

Concerning the adjustment to topographic relief, more will be said under the heading of *How to Record*.

5. *Observations within Areas between Boundaries.*—Too exclusive an attention to the tracing of geologic boundaries often results in a neglect of the necessary observations to be conducted within the areas so outlined. They are of equal importance with boundaries. A few of them may be mentioned here for the sake of stimulating discussion. These are, lines of faulting, structural deformations of formations such as folds and dip observations, changes in texture and mineral composition, inclusions of wall rocks and internal segregations in igneous rocks, directions of prevailing schistosity or gneissoid texture in metamorphic rocks, and many others.

(*d*) WHERE TO RECORD.

1. *General.*—The geologist will perforce come from the field with some of his information in the form of a mental record. If *much* be left to memory, such notes as are taken often prove unintelligible and cannot be used after the lapse of a short time, nor will they ever be serviceable to others. It is therefore desirable to have all data actually recorded. It is also true that mental records are secured chiefly through the very process of recording data, so that even if the report could be written entirely from memory, full note-taking could not be eliminated with success.

The extent to which geologic observations should be recorded on a map or in a note book is one of the most persistently recurring problems with which a geologist has to contend. Some geologists use a map simply for the purpose of determining their location. All data of every kind are then written in their note books. Other geologists discard the note book almost completely and by using a map of large scale and cultivating a microscopic method of record, they place all of their observations on the map. Between these two extremes, workers will be found who use all the intermediate gradations. It is needless to say that either one of these extreme instances is generally unsatisfactory and that some intermediate system, where part of the notes are recorded on the map and part in the note book, has been found most advantageous.

2. *Cross Reference Methods.*—Inasmuch as both maps and note books are to be used, it is absolutely indispensable that the geologist in his office work should be able to pass immediately from any given locality on the map to the notes referring to that locality in his note book, or to the specimens collected from that locality in his collections. He should also be able to open his note book at any point and instantly locate on the map the place to which the notes refer..

Much of the space occupied in books on field geology is taken up, and justly so, with a discussion of the various methods of cross reference by which all information concerning any given locality may be instantly brought together. A few of the more common methods may here be briefly described.

There are four possible ways in which cross reference can be made from map to note book:

1. The Descriptive Method.
2. The Bearing Method.
3. The Coördinate Method.
   (*a*) Actual Coördinates.
   (*b*) Imaginary Coördinates.
4. The Route Method.

1. *The Descriptive Method.*—The most obvious way to describe a locality is by written description; thus, one might say:

"Increased foliation and distortion was noticed half-way up the hill, about a mile along the second road to the east from Lexington and on the northeast corner of a corn crib on the farm of Mr. Tom Jones."

When the writer has finished referring to a certain place, he has spent ten minutes of valuable time and written something that he knows nobody else can understand and which he himself will not later be able to decipher, or at best only at the expense of much valuable time. This system is therefore now but little used.

2. *Bearing Method.*—Another method is by recording sights on known points; either three intersecting sights are used, as in three-point work, or single sights and estimated distance, thus:

"Specimen collected one-half mile N. 30° W. from meetinghouse."

This involves (1) Description of meetinghouse and its location, (2) time in recording sights, (3) estimate of distance that may be incorrect and makes it necessary to plot out angles, etc., each time reference is made from notes to map. It is cumbersome, slow, not easily used, and inaccurate.

3. *Coördinate Method.*—Many geologists now use some form of the coördinate method. This consists in dividing the map into rectangles referred each to an abscissa and an ordinate. Any point may then be located by the simple use of a few letters. For this purpose the map may be divided into a few equal rectangles which are numbered in Roman numerals. Each one of these larger rectangles is the unit upon which the coördinates are based. When a topographic base is available, the basic rectangles are the "projection lines," of latitude and longitude.

The map is then cut up into squares about one-fourth to one-half inch larger than the actual rectangle, so that observations of important outcrops do not run off the map and cause confusion. The map is now posted in the note book whose page is a little larger than the map. The number of the rectangle is put at the top of the page.

Actual Lines.—Lines are now drawn, beginning at the top and left, parallel to the projection lines. These are drawn at stated distances apart, say 1,000 ft. (if the map is on a scale of 1 mile to

an inch). Distances can then be readily estimated in feet without the need of a scale. It is well not to have them too far apart, as then descriptions of locations are too indefinite,—one-fourth to one-half inch are good approximate limits.

From the top down, these spaces are lettered at the left, and from left to right across the top *outside of the map*. Any location under discussion in the notes can then be stated at once, thus: I–E–6, which will show the exact square. If it is desired to get even closer than this, it can be amplified thus, I–E–6–SW, and if great accuracy be desired a little dot can be indicated on the map and added to the statement in book, I–E–6–SW[·]. Coördinates such as this can be used on labels of specimens or even put actually on the specimens in indelible ink, if desired. That is not usually necessary.

In recording these coördinates in the note book, they should be placed at the left in the margin and outside of the body of written notes.

After return from the field, it will often be convenient to index the note book further, as follows:

I–A–1 PP 10, 14, 84, 106, 42, 58.
I–A–2
I–A–3 PP 3, 8.
I–A–4
I–A–5
I–A–6 PP 21, 87.

etc., until each square on the map is listed. Now put down the pages where data on these coördinates are discussed and an automatic index is secured by which all the notes on any given area of country can be at once consulted.

Imaginary Lines.—Some geologists do not like to obscure their maps by drawing actual lines on them. This may be avoided by writing coördinates on an L-shaped piece of celluloid which may be placed at the upper and left side of the unit rectangle. It may be used even on maps not inserted in the note book. This system was devised by Prof. J. Barrell. Location of squares

can then be found by intersecting pencil and ruler, etc. This is about as accurate as actual lines and, as stated above, has the advantage of not obscuring the map.

4. *Route Method.*—When ordinary cross traversing is done by whatever method, a coördinate system need not be used, though it is well to have it in case of necessity, for traverse stations form an automatic cross reference. Thus, if the traverse line be a road or a traverse which is made from one point which *can be at once located on the map* to another, each point can be marked on the map and in the book. A letter should be used every day and at the head of each day's notes should be written (whether use of this method is intended or not). No other letter will be used on that day. Stations will then be A, A_1, A_2, A_3, etc. As each letter then signifies a definite date, and notes are consecutive and dated every day, any location can at once be found on the map and in the note book because the letters follow after one another in alphabetical order. Furthermore, any point can be discussed by saying between A and A_1, using number of feet along traverse.

Such a system of a letter for a day has the advantage of making an extremely simple and automatic cross reference system and can be applied to *any* form of traverse and even to plane-table work.

(*e*) HOW TO RECORD.

1. *Choice of Method.*—The methods by means of which geologic data are recorded, later outlined, are methods of *recording notes,* not of *location* or *measurement.* The way in which measurements have been made will to some extent affect the system of record so that an understanding of it is essential. Numbers of different schemes are in successful use and the choice will depend upon (1) the nature of the geology, (2) the time available, (3) the scale of the map, and (4) the purpose for which the survey is made.

In map records an understanding of the intersections of outcrops with topography is essential before methods can be intelligently discussed.

2. *The Relations between Geologic Surfaces and Topographic Relief.*—Maps are merely horizontal projections. With contour maps it is the lines of equal elevation that are projected; with geologic maps it is the intersections of geologic surfaces such as geologic boundaries, faults, etc., with the topographic relief, that are projected. Successful mapping therefore necessitates a clear understanding of the nature of geologic surfaces and of the descriptive geometry involved in their intersection with topographic relief.

(*a*) *Geologic Surfaces.*—Each limit of any geologic formation is some form of surface whose thickness is 0. Its intersection with the surface will hence appear on a map as a line—the thinner the line the more exactly the map approaches a representation of the truth. The same is true of faults. If a fault be infinitely narrow, it constitutes a surface whose thickness again is 0. If it be a wide zone, it constitutes two such surfaces whose interspace is filled with breccia or other rock substance. Ore bodies likewise are bounded by surfaces of no thickness which appear in outcrop as lines.

Geologic surfaces are practically never *perfect* planes. They approach planes so closely, however, in some instances that they may be so considered in field work. The nearest approach to planes is found when they are the limiting surfaces between sedimentary layers which are either undisturbed and horizontal or have been tilted in folds of such large curvature that they constitute inclined planes within the limited area of a given map. Faults are more rarely planes, though portions of them on maps of large scale approximate planes. Folded strata, most faults, the bounding surfaces of large igneous masses, and of some large ore bodies and veins are surfaces of complex curvature. Extremely irregular igneous bodies and most ore deposits yield surfaces of such extremely irregular configuration that they cannot be well included in either of the above groups.

(*b*) *Intersection with Topography.*—The making of any geologic map consists in greater part of the determination of the outcrops of such surfaces—for the coloring of the intervening

areas offers no difficulty. The horizontal projections of the intersections of these geologic surfaces with the complex features of topographic relief yield the lines of outcrop. No geologic maps can be constructed where all points on a geologic surface can be actually located. Either the geologic surface is covered by débris, or vegetation, and appears only here and there, or time permits the location of only a few points along its course. It therefore becomes necessary to use, either consciously or unconsciously, the methods of descriptive geometry to locate the intervening undetermined portions. Geologic surfaces may be classified, in relation to character of surface and position, as follows:

Plane Surfaces. (Boundaries between strata and limited portions of faults.)
In vertical position.
In horizontal position.
In inclinal position.

Surfaces of Complex Curvature. (Folded strata, most faults, some igneous boundaries, simple veins, and the outlines of some ore-bodies.)

Surfaces of Extreme Irregularity. (Igneous contacts, outlines of irregular ore-bodies.)

Only a few general statements need, therefore, be inserted at this point. With plane surfaces, comparatively few points are necessary if dips are constant and the topography represent the bed rock and not the covering of débris. With surfaces of complex curvature, a system of structure contouring will be indispensable for accurate work in addition to the location of a larger number of points. With excessively irregular surfaces such as igneous contacts, only the absolute location of an infinite number of points can secure absolute accuracy. Outcrop lines drawn between located points will be more or less approximations. If they are sketched in the field from actual observation, they may be made fairly accurate, if obscured by débris or plotted in the office, they must necessarily be wholly speculative. It is, therefore, essential that as many points as possible on extremely irregular outcrops of surfaces of this kind should be determined by actual

survey, for their geometry cannot be inferred and their outcrops cannot therfore be indicated by geometrical methods. A paper dealing with the use of structure contours in mapping and in practical mining operations would be of great value and it is hoped that such may be offered as a contribution to this discussion.

3. *Methods in Use for Recording Observations in Surface Geology.*—A few of the methods in use may be briefly stated here—their detailed description will be left to various contributors. The following, as stated in the outline, are the most common:

α. Boundary tracing methods.
  i. Pencil crayon method.
β. Cross traverse methods.
  i. Letter traverse method.
  ii. Profile traverse method.
γ. Multiple exposure method.

α. *Boundary Tracing Methods.*—i. Pencil Crayon Method: This method consists in following the boundary of a geological formation as closely as possible and indicating it upon the map by a line. Crayons are then used to show the rocks on either side of the boundary. Geological boundaries will be more or less accurate according to the instruments by means of which their position is determined. It may be done simply by the eye assisted by the barometer and hand level. If a good topographic base is available and the scale of the map is small, the results will often be within the limits of allowable error for that scale. Greater accuracy is obtained when various methods of accurate survey are used for the determination of the boundary. This may be done by compass and pacing, by planetable methods, or by accurate survey with a transit.

This method has the disadvantage of not distinguishing data founded on inference from data founded on observation. In drawing a boundary in the field with a pencil, it is generally done continuously and areas of any unit formation are colored as the work progresses. The actual limits of outcrops are not shown and the observed points on boundaries not distinguished from

those connected by inference. To make it serviceable in this particular some method of distinguishing observed data from inferred data should be devised.

β. Cross Traverse Methods.—i. Letter Traverse Method: If instead of following boundaries the routes of available travel are made the basis for survey, a different system of record results. Roads or paths, if such are indicated on the base map, are chosen preferably at right angles to the strike of formations and a series of angular traverses independent of boundaries are made across the map. The result is a series of disconnected points along a geologic surface which must later be connected by inference or by the additional use of the boundary tracing method. If these traverses are made with the aid of a base map upon which roads, railroads, trails, etc., are indicated and are present in considerable numbers, the map is already, so to speak, triangulated, and if the recognizable points are carefully observed, recording on the map consists simply in indicating the nature of rock boundaries crossed and other data observed at the proper point. Notes taken in the note book are referred to the map by means of stations indicated at salient points. If the letter system, A, A_1, A_2, etc., described on page 86, be used, this method yields an excellent automatic cross reference. If the map has no culture indicated, and topographic relief does not show in conspicuous points, or if no map is available, the work is done by a series of closed (or open) traverses, which are recorded just as any survey notes, and the map is then but little used for record. In the notes a tie is made to some few starting stations and the geology written down together with the measurements, both angular and horizontal, for each observation. The map is not then constructed until the field work, at least for that day, is completed. Cross traverse methods have the advantage of yielding an examination of both boundary and intervening area at the same time and result in the omission of fewer features in the center of bounded areas. The method is excellent as applied to regions of highly folded sedimentary rocks where boundaries are not numerous and where horizontal measurements are of the utmost importance.

ii. Profile Traverse Method: A modification of the traverse method is that suggested and in use by Mr. M. R. Campbell, of the U. S. Geological Survey. It consists in recording geological notes on a running profile which is barometrically checked at each station and the notes on the profile are then later adjusted to accurate sections with proper corrections of profile. Stations are indicated on the running profile by the same letter system of a letter for a day, as described on page 86. Horizontal distances are neglected as they are later adjusted by the accurately made sections. This method is described in detail by Mr. Campbell in the *Transactions of the Institute of Mining Engineers,* Vol. 26, pp. 298 to 315. It is applicable only to regions of sedimentary rocks with low dips and to regions where the topographic relief is sufficient to make barometer readings serviceable and to yield frequent checks at recognizable stations. With rapidly alternating sedimentary rocks it is extremely rapid and accurate.

γ. *Multiple Exposure Method.*—When geology is exceedingly difficult and a large scale map is used and great accuracy desired, another method is often used. In this method every outcrop is located and examined and mapped from actual observation, work being especially concentrated where it is believed that boundaries are likely to be found. This has been much used in the Lake Superior iron region.

Every exposure is mapped and then when all is done the boundary is drawn from this data. This method has the advantage of giving the geologist *all* of the available data and if the outcrops are *located* with care it is the most accurate method of all. It has also a great negative value because it shows where outcrops of veins, etc., cannot possibly occur. Like the other methods of work, it depends for its accuracy upon the care with which the measurements are made. In the Lake Superior region, for instance, outcrops are referred to section corners as these are the only available points which may be recognized both on the map and in the field. With other satisfactory tie points this method can also be utilized in any region. It is especially serviceable in conjunction with one of the other methods for unravelling especially complicated portions of elsewhere simple geology.

4. *Methods of Record in Use for Underground Work.*—Very little has been written on the methods for making and recording observations in mine workings. The subject is so large that it can be only briefly touched upon here. The geologist may go underground with or without an adequate map of the underground workings. If the workings are very simple and of limited extent, he can make a satisfactory map by compass and pace survey—if they are extensive, it is quite useless to attempt any work at all without either securing a map from the company or having an accurate survey made. Underground structural problems are problems in solid geometry and unless great accuracy of location is secured, observations on the several levels cannot be correlated with one another.

Presupposing an accurate map, a brief synopsis of one method of procedure may be given. Preparation for the work should be made by plotting in the note book each separate level of the mine. This may best be done in a note book ruled in inches and tenths. Since mine maps are generally referred to coördinates, these squares can then be used to transfer mine workings. A scale of 100 feet to an inch is the most satisfactory scale. Anything larger occupies too much space to be transferred to the note book, and anything smaller does not permit the recording of detail. Where possible, a key map containing *all* levels should be plotted in the note book just before the maps of the separate levels. This may then be used in referring the levels to one another.

After maps have been prepared, they should be put in shape for recording notes. Mine observations are made (1) on horizontal drifts, crosscuts, or tunnels; (2) on raises and shafts; (3) on inclines, and (4) in stopes. The notes made along horizontal workings should be cross referenced in the same way as a surface traverse. A letter should be placed on the map either at a tunnel intersection or other recognizable point, or one of the survey stations established by the surveyor when the map was first made. These should be indicated by letters A, A_1, A_2, B, B_1, B_2, etc., a different letter for each separate day's work.

Raises should be *numbered* on the map and a corresponding list made, thus:

Raise 1,
Raise 2,
Raise 3, etc.

This should be done *before* entering the mine in order that the most possible mechanical labor be eliminated and the geologist left free for recording geologic observations. Sections of raises can then be at once written in the proper place without delay. A place for the shaft section, giving observations of separate levels, datum to which referred, total depth of shaft, and rocks cut in sinking it, should be prepared in the note book before entering the mine. A separate set of pages should be devoted to records of diamond drill hole records, all of which should be indicated on the mine map without fail. Definite names should be given on the mine map to the several stopes and these should be carefully used in description. A condensed form of the consecutive pages of the note book before entering the mine would then appear as given below:

MATCHLESS MINE.

Shaft. (Vertical or inclined and at what angle.)

	Rocks Passed Through in Shaft.	
Elevation collar	Wash.	20
Datum referred to.....	White Porphyry.	250

Position of collar. (Artificially raised or at ground level.)

Depth of 1st Level.....	Limestone	100
Depth of 2d Level.....	Quartzite	20
Depth of 3d Level.....	Andesite	300
Depth of Sump.	Granite	25

(*Insert plan map of all levels here.*)

1st Level.

List of Raises.	List of Winzes.
Raise 1.....	Winze I.....
Raise 2.....	Winze II.....
Raise 3.....	Winze III.....
Raise 4, etc.....	Winze IV., etc.....

(*Insert plan of 1st level here.*)

Jan. 20, 1912—Traverse A., etc.

4. *Collection of Material.*—In addition to the construction of a map and the recording of notes and observations, the geologist also collects specimens of rocks and ores. He is at once confronted with two problems, "What shall I collect?" and "How shall I number and catalogue my material so that it may be most easily used and the operations of collecting and numbering be made to occupy the least possible time in the field?"

Space is not available for detailed discussion of these questions. A few general applications are, however, here admissible. The main difficulty which nearly all geologists experience in making collections is the securing of typical material. A visit to a mine will, for instance, frequently show great quantities of a certain run of mine ore. There is so much of it and it seems so common that attention is drawn from it to the exceptional types, such as remarkably fine crystals, unusual minerals, and other exceptional features. Returning from the field, the geologist frequently discovers that he has obtained a large number of specimens representative of exceptional and often unimportant features, but has altogether neglected to secure typical material.

It is as important that ready passage from note books to specimens be possible as from note book to maps. It is, therefore, desirable that some automatic system of specimen numbering should be adopted. That which many geologists now use is to draw a prominent square around the number in their notes. This will stand out at once from the other notes on a page. As the numbers used for specimens throughout the various note books will be consecutive, from the number of a specimen a man may at once turn to his note books and easily find the notes which refer to that specimen. This has the great advantage over any other system that no record need be made on the label as to the page of the note book on which the specimen is described and no specimen list need be compiled. A large amount of work is eliminated.

Other systems for passing from specimens to note books and maps have been suggested in Mr. C. W. Hayes's admirable little book on "Field Geology." Still others the writer feels certain

can be suggested and discussed by those who are later to contribute to this discussion.

PREPARATION OF REPORT FROM COLLECTED DATA.

Office work in the compilation of a report consists in part of:

1. Preparation of Surface Map.
2. Construction of Geologic Sections.
   (*a*) Choice of section lines.
   (*b*) Checking of intersecting sections.
   (*c*) Methods for plotting faults and boundaries.
   (*d*) Symbols for representation of rocks.
3. Construction, use, and value of stereograms.
4. Interpretation of geologic records and collections.
   (*a*) The use of analyses and assays.
      (1) Methods of recalculation.
5. Writing the Geologic Report.

Concerning each one of these operations, there is much that may be added to the present discussion. This is perhaps especially true in regard to the interpretation of geologic results. Many short cuts for the calculation of mineral composition, interpretation of analyses, etc., have been devised. Admirable systems also are now used for the construction of stereographic projections of mine workings, and topographic relief. The writing of reports themselves seems to me to merit very serious consideration. This is particularly true in view of the somewhat stereotyped form in which the reports of many official surveys are frequently cast. It is believed that some criticism of the arrangement of material and its presentation would be an excellent addition to the present discussion.

The writer is conscious that the outline of geologic field work as given in the above pages is nothing more than a skeleton summary of the different phases of work to which contributions may be made. Detailed discussions have for the most part been advisedly omitted, with the hope that others will contribute detailed discussions.

J. D. IRVING.

REVIEWS

The Coal Fields of King County, Washington. By GEORGE WATKIN EVANS. Geological Survey of Washington, Bulletin No. 3, 247 pages, 23 plates, including geologic map in pocket, and 59 figures, 1912.

This is indeed a very commendable volume and is far ahead of previous reports on the coal fields of the state. Its superiority is in part due to the fact that it contains detailed maps and descriptions of the coal beds, but more largely to the fact that it has been prepared by a man thoroughly acquainted not only with the theoretical questions regarding coal, but also with the practical side of coal mining and the preparation of coal for the market. Despite the lack of good base maps, Mr. Evans has succeeded in representing the stratigraphy and structure of the region in a very satisfactory manner, and in this respect his report would serve as a model for some of the state surveys of the eastern states where excellent and modern maps, although available, have not been used to represent the outcrops of coal beds even where the coal is the principal mineral resource.

Mr. Evans devotes a chapter to the geology of coal, two chapters to the geology of these coal fields, one to the classification of coal mines, one to mining methods, one to the character of the coal, and one to the market for King County coal. In each of these chapters the subject is clearly presented and well discussed so that the reader may obtain a large amount of valuable information concerning coal in general and about King County coals in particular.

The attitude and location of the coal beds in the various mining centers are well described in the text and illustrated in the plates and figures, but there is a strange lack of coördination between these two parts of the report. Although, according to the list of illustrations, there are twenty-three plates and fifty-nine figures, there are by actual count only ten references to illustrations in the text. The reader is impressed with the idea that the text and illustrations have been prepared separately and that the author forgot to supply the needful cross-references. This also gives the impression that the illustrations are used solely for embellishment, but this is not the case as the plates and figures are all appropriate and add much to a clear understanding of the subject.

Most of the sections of the coal beds, and these generally are represented graphically, are so placed that they appear in their proper posi-

tions, but other illustrations are far from that part of the text dealing with them, and in some cases the reader fails to make the proper connection. All this is due to lack of care on the part of the author in seeing that the figure is given its proper place and also that it is referred to in the text. Young authors would do well to make it a rule to mention every text figure, plate, and map, and not leave their identification to the ingenuity of his reader.

The least satisfactory part of the report is the chapter on mining methods. This chapter is fairly well illustrated by mine maps, but many of these are not even mentioned in the text, and those that are mentioned are not well described. This is particularly true of the photographs of mine models in Plate II. Unfortunately one of these models appears wrong side up, but this could be excused if the models were adequately described so that the reader could readily grasp their meaning.

The composition of the coal is well shown by the analyses which are incorrectly accredited to the United States Geological Survey. It is true that the sampling was done by a geologist connected with that organization, but the chemical work was done at the Pittsburgh laboratory of the Bureau of Mines. Although the sampling and the analyzing were carefully done, and the number of samples adequate to fairly represent the coal of the county, the analyses as published have very little value for the reason that the author failed to state what part of the coal bed is represented by each sample. To many persons this may seem to be a degree of refinement not required in practical work, but this is a great mistake. The value of chemical analyses depends almost entirely upon the sampling and in coal beds containing so much foreign material as those of Washington it is all important to know exactly what benches of coal and what partings were included in the sample. The sampling of a coal mine should be as carefully done as that of a gold mine, and the location and description of the sample should be as carefully noted and furnished to the reader for his information.

On the whole the bulletin is very satisfactory, and doubtless will be extremely useful to all persons interested in the geology or coal resources of King County.

MARIUS R. CAMPBELL.

Practical Field Geology. By J. H. FARRELL. Including a guide to the sight recognition of one hundred and twenty common minerals, by ALFRED J. MOSES. New York, McGraw-Hill Book Company.

This little book of 273 pages is attractively bound in flexible leather and fits conveniently in the pocket. The matter within loses nothing by contrast with the pleasing exterior and other excellent physical features of the work. The writer has read widely, observed carefully, and written

clearly. The style is, moreover, delightful: the reader feels almost that the operations described are actually being done; that he is in the field, working with the writer, and moreover, that he is in good company.

Chapters I.–III. are on the planetable and topographic mapping; the discussion is clear and illustrations are well chosen. Chapters IV.–IX. are on geologic mapping and the interpretation of geologic maps. They include also a discussion of mapping underground with some excellent illustrations of geologic maps of mine levels. Chapters X. and XI. treat the mineral classification and the surficial alteration of ore deposits. Chapter XII. is on rock classification; this digest of eleven pages contains many valuable criteria applicable in the field. Chapters XIII.–XV. describe the outfits required for various kinds of work and the methods of prospecting in some detail.

In the supplement by Professor Moses, one hundred and twenty minerals are classified by simple field tests involving only color, streak, and approximate hardness. Fifty simple tests for confirmation are described, and the tests appropriate to each species are indicated by numbers after the description of the species.

This book should prove very useful to unseasoned geologists and prospectors, and the seasoned ones will find much of value in it.

W. H. Emmons.

SCIENTIFIC NOTES AND NEWS[1]

THE TWENTY-FIFTH ANNUAL MEETING of the Geological Society of America was held in New Haven, Connecticut, on December 28–31. The business sessions of the meeting took place in Lampson Hall, one of the buildings of Yale University. Among the papers that were read, many were of unusual interest to students of economic geology; perhaps special mention might be made of the following:

Fred E. Wright, "Experimental Geology, One of the Large Subdivisions of Geology."

Harry Fielding Reid, "Report of Committee on Nomenclature of Faults."

Arthur L. Day, "A Preliminary Report of Certain Physical and Physico-chemical Observations at the Kilauea Crater."

Chase Palmer, "A New Classification of Natural Water."

Clarence N. Fenner, "The Various Forms of Silica and Their Mutual Relations."

Thomas L. Watson and Stephen Tabor, "Igneous Complex of High Titanium-Phosphorus-Bearing Rocks of Amherst-Nelson Counties, Virginia."

Joseph T. Singewald, Jr., "The Microstructure of Titaniferous Magnetites."

I. C. White, "The Gulf Coast Petroleum Fields of Mexico Between the Tanesi and Tuxpan Rivers."

Edward C. Jeffrey, "The Nature of the Substance known as Mother of Coal and its Relation to the Process of Coal Formation."

[1] Geologists, mining engineers, and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Edward C. Jeffrey, "The Inadequacy of the Sapropelic Hypothesis of the Origin of Coal."

Many other papers of value, but with less immediate bearing on the problems of economic geology, were presented and read, and it would seem to some of those who attended the meeting that the papers were as a whole of very much greater interest than those which have been read for some years.

Among the papers above mentioned in detail, three merit further comment. The report presented by Mr. Harry Fielding Reid, on the nomenclature of faults, represents the work of a committee upon this subject for a considerable period of time. It is interesting to note that this report is the outcome of the discussion originally inaugurated in this Journal. The results which Mr. Reid presented excited considerable discussion, and before the report has been completely accepted it is probable that the matter will be taken up by the International Congress. If so, it is presumable that the development of a satisfactory classification and nomenclature for faults may result.

The second paper of striking interest is that of Mr. Arthur L. Day, on the Kilauea lavas. Mr. Day succeeded in obtaining from one of the fumeroles in the neighborhood of one of the Hawaiian volcanoes water vapor which was condensed in a tube in such a way that it seems probable that it represents original magmatic water. The display of the tube containing this water lent a certain dramatic interest to the presentation of this paper.

The third paper which it seems to us deserves especial mention is that of Mr. Joseph T. Singewald, Jr., on the "Microstructure of Titaniferous Magnetites." The material was prepared according to the methods originally suggested in this Journal by Messrs. Campbell and Knight. The value of the results obtained in this particular investigation is perhaps greater and more obvious than those obtained from any other problem to which this method has been applied. The long disputed question as to the condition in which ilmenite and magnetite are related to one another in titaniferous magnetites has become instantly obvious in all of the slides to which this method of research was applied.

Mr. Singewald is to be more than congratulated on the very valuable piece of work which he has been able to present to the society.

The presidential address of President H. L. Fairchild, the retiring president, was delivered in Byers Hall on the 28th. On the same evening a smoker was given to the members of the society and their friends, which was largely attended.

The excursion originally planned for Sunday, December 29, was omitted owing to the unsatisfactory weather conditions. A series of memorial speeches to Professor James D. Dana was given in Lampson Hall on Sunday evening. On Monday night the annual dinner of the society was held, with Professor James F. Kemp as toastmaster. The menus contained reproductions of paintings of Benjamin Silliman and J. D. Dana. The sessions of the society closed on Tuesday, December 31.

IN THE COURSE of geological work, correspondence between the various geologists of the country and the official state geologists becomes necessary. For this reason, and also because a list of state geologists is not always easily accessible, the following table, giving the names and addresses of the state geologists in the several states, is presented. This list represents the latest incumbents in office and their present addresses.

Alabama	Dr. Eugene A. Smith	University, Ala.
Arkansas	N. F. Drake	Fayetteville, Ark.
California	W. H. Storms	San Francisco, Cal.
Colorado	Prof. R. D. George	Boulder, Colo.
Connecticut	Prof. W. N. Rice	Middletown, Conn.
Florida	Dr. E. H. Sellards	Tallahassee, Fla.
Georgia	Dr. S. M. McCallie	Atlanta, Ga.
Illinois	F. W. DeWolf	Urbana, Ill.
Indiana	Edward Barrett	Indianapolis, Ind.
Iowa	Geo. F. Kay	Iowa City, Ia.
Kansas	Prof. Erasmus Haworth	University of Kansas, Lawrence, Kansas.
Kentucky	J. B. Hoeing	Lexington, Ky.
Louisiana	Prof. G. D. Harris	Baton Rouge, La.
Maine	C. Vey Holman	Brunswick, Maine.
Maryland	Prof. W. B. Clarke	Johns Hopkins Univ., Baltimore, Md.

Michigan	R. C. Allen	503 Hollister Block, Lansing, Mich.
Minnesota	Prof. W. H. Emmons	Univ. of Minnesota, Minneapolis, Minn.
Mississippi	Prof. E. N. Lowe	Jackson, Miss.
Missouri	Prof. H. E. Buehler	Rolla, Missouri.
Nebraska	Prof. E. H. Barbour	Univ. of Nebraska, Lincoln, Neb.
New Jersey	Dr. H. B. Kümmel	Trenton, N. J.
New York	Dr. J. M. Clarke	State Museum, Albany, N. Y.
North Carolina	Dr. J. H. Pratt	Chapel Hill, N. C.
North Dakota	Dr. A. G. Leonard	Grand Forks, N. D.
Ohio	Prof. J. A. Bownocker	Columbus, Ohio.
Oklahoma	Prof. D. W. Ohern	Norman, Okla.
Pennsylvania	R. R. Hice	Beaver, Pa.
Rhode Island	Chas. W. Brown	Providence, R. I.
South Dakota	Prof. E. C. Perisho	Vermilion, S. D.
Tennessee	A. H. Purdue	Capitol Annex, Nashville, Tenn.
Texas	W. B. Phillips	Austin, Texas.
Vermont	Prof. Geo. H. Perkins	Burlington, Vt.
Virginia	Prof. T. L. Watson	Charlottesville, Va.
Washington	Prof. Henry Landes	Seattle, Wash.
West Virginia	I. C. White	Morgantown, W. Va.
Wisconsin	Dr. E. A. Birge	Madison, Wis.
Wyoming	C. E. Jamison	Cheyenne, Wyo.

ALBERT DUDLEY BROKAW has been made an instructor in mineralogy and economic geology in the department of geology at the University of Chicago.

IN THE UNIVERSITY of Manitoba, Winnipeg, Canada, R. C. Wallace has been made professor of geology and mineralogy.

THE STATE GEOLOGICAL SURVEY of Tennessee is the only state survey publishing a monthly magazine. Volume Two of "The Resources of Tennessee" is just completed. Timely articles on the mineral wealth, water resources, water power possibilities. road improvement, and kindred subjects, call the attention of people within and without the state to its opportunities.

THE OKLAHOMA GEOLOGICAL SURVEY published in December, 1912, in Bulletin No. 15, the Director's Biennial Report and an

account of the mineral production of Oklahoma from 1901 to 1911.

L. D. BURLING, of the Smithsonian Institution, went to the Canadian Geological Survey on January 15.

MYRON L. FULLER, formerly in charge of groundwater investigations in the eastern United States for the U. S. Geological Survey and now manager of the Associated Geological Engineers, has been retained by the city of San Francisco to investigate the artesian supplies of the Livermore Valley, the quantity of which is a controverted point in the negotiations for the purchase of the properties of the private water company now supplying the city.

AT A MEETING of the Geological Society of Washington held on December 11, the presidential address was delivered by T. W. Stanton, entitled "Some Variations in Upper Cretaceous Stratigraphy."

ON MONDAY, December 16, the annual dinner of the New York Academy of Sciences was held at the Hotel Endicott, New York City.

ON FRIDAY, December 20, Mr. H. B. Pullar delivered a lecture at Columbia University on the subject of "Mining of Gilsonite and the Manufacture of Gilsonite Products."

PROF. C. K. LEITH, of the University of Wisconsin, spent the summer in Europe, and during the fall was one of a party which studied the geology of the northwest highlands of Scotland under the leadership of Drs. Peach and Horne of the Geological Survey of Scotland. Since returning from Scotland, Dr. Leith has been engaged in the estimates of tonnage of Michigan and Wisconsin iron mines for the tax commissions of the two states.

DOUGLAS WILSON JOHNSON has become associate professor of physiography in Columbia University, New York City.

G. E. ANDERSON, professor of geology, New Mexico School of Mines, represented his institution at the inauguration of Dr. David Ross Boyd as president of the University of New Mexico at Albuquerque, November 9, 1912.